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TECHNOLOGY AND BLOOM'S TAXONOMY:
TOOLS TO FACILITATE HIGHER-LEVEL LEARNING IN CHEMISTRY

by

Matthew Earle Morgan

A thesis submitted in partial fulfillment
of the requirements for the degree

of

Doctor of Philosophy

in

Chemistry

MONTANA STATE UNIVERSITY
Bozeman, Montana

November 1997

ABSTRACT

This research project ties together chemistry data acquisition technology, introductory chemistry laboratory experiments, and Bloom's *Taxonomy of Educational Objectives* into a unified learning model. The goal is to provide faculty and introductory chemistry students with the tools and exercises to experience higher levels of learning, as defined by Bloom's taxonomy. The tools developed as part of this project include data acquisition hardware and software, communications software, and computer simulations that enable higher-level learning situations.

A series of five experiments using a discovery-based teaching model are developed as part of the learning model. The experiments bring together the hardware tools, software tools, and learning model to place students in situations that require students to use critical thinking skills and experience higher-level learning. Content-related application problems are also included in the experiments. The experiments are divided into three chemistry units of instruction that build on each other, but can also be used independently.

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Finally, students were surveyed in an attempt to measure the effectiveness of the learning model. Students were evaluated on chemistry concept retention, as well as their perception of learning. They were also asked how well they enjoyed this form of learning.

Along with the tools themselves, this project provides templates that can launch future work in this area. The learning model, data acquisition tools, and experiment writing templates are developed here to provide curriculum builders many new ways allow their students to achieve higher-level learning.

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APPROVAL

of a thesis submitted by

Matthew Earle Morgan

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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CHAPTER 1

INTRODUCTION

Since the beginning of organized education, educators and administrators have attempted to improve the learning process. In the last forty years a huge amount of time, effort, and federal funds have been devoted to this cause. Despite these efforts, increasing financial constraints on individual schools and colleges have made achieving quality learning more difficult. In many situations, lecture sections have become larger, while laboratory time has decreased. Students are primarily tested using machine-scored multiple-choice questions, and they rarely learn course material beyond the level necessary to answer these types of questions.

In an attempt to reverse this trend toward assembly-line education, the Advisory Committee to the National Science Foundation Directorate for Education and Human Resources has published a review of undergraduate education titled, *Shaping the Future: New Expectations for Undergraduate Education in Science, Mathematics, Engineering, and Technology*. The committee's stated goal is that "all students have access to supportive, excellent undergraduate education in science, mathematics, engineering, and technology, and all students learn these subjects by direct experience with the methods and process of inquiry."¹

Two questions raised by this goal, then, are (1) How is "excellent undergraduate education" defined? and (2) How can schools, colleges, and universities cost-effectively teach using "methods and process of inquiry?" The purpose of this project is to address these two questions.

Higher levels of learning and thinking skills are defined in this project using Bloom's *Taxonomy of Educational Objectives*. The tools used to achieve higher levels of student learning are computer-assisted data acquisition and computer simulations. The emphasis on tool development is making data acquisition tools less expensive and easier to use.

All professors and school administrators want students to experience higher-quality learning, but the means and methods required to achieve this goal are often beyond the schedules and budgets of many colleges and universities. One method to achieve increased student learning is to use advanced educational technology to reduce demands on both time and budgets, and to place students in situations where they must use higher level thinking skills. Technology has been applied to many areas of education, including chemistry. Periodicals such as the *Journal of Chemical Education* and *The Chemical Educator* describe new methods and devices designed to measure chemical phenomena in an educational setting. Of all these innovations, the most influential technological improvement in chemistry education has been the inclusion of personal computers. A computer's ability to acquire, store, and analyze experimental data has markedly changed the way students learn in chemistry lecture and laboratory. Properly employed, computers are an important tool in enabling higher levels of student learning.

Computers by themselves cannot increase learning, however. Administrators cannot merely purchase computers, set them in classrooms, and expect the new technology to magically transform the nature of education. Improperly used, computers have resulted in lost productivity due to a distracting array of new features and time required to troubleshoot problematic hardware and software.² Critics of computer use in education assert that schools spend money on computers that have few functions beyond entertainment for teachers and students.³ This combination of misperceptions and ill planning have resulted in disillusionment and potential abandonment of new technology for education.⁴

Educational technology exists in chemistry classrooms and laboratories, but its use and its potential benefits are not being realized. A recent survey of two-year and four-year university chemistry departments by Abraham and colleagues indicates that only 12 percent of the schools surveyed use computers in two or more laboratory activities.⁵ This lack of use can be attributed to four main obstacles:

- Computers are expensive.
- Computer-driven applications can be difficult for students to understand.
- Few content-oriented applications effectively use new technology.
- Faculty have not had opportunities to learn to effectively use these tools.

Technological tools can benefit chemistry education, but these tools must be easily understood and properly employed in the educational environment.

Previous Work Incorporating Technology

Appropriate use of technology already has reaped great rewards in chemistry education. In the late 1980s, Amend, Furstenau, and others did pioneering work in applying computers to introductory chemistry laboratories.⁶⁻⁹ They combined computer interface and sensor technology to develop a system for automated data acquisition and experiment design. The results of their work showed that experiments can be designed so that students using computers in the laboratory spend less time on data acquisition and more time designing experiments and analyzing their data. Expanding on this original work, a consortium of colleges and universities called Computers in Chemistry Laboratory Instruction (CCLI) created many experiments that make use of computer-controlled data acquisition.¹⁰⁻¹⁴

The inclusion of computer technology in the laboratory has enabled students at Montana State University and other schools to perform a greater variety of experiments and reduce the time required to perform specific laboratory procedures. Figure 1 shows that in traditional laboratory experiments, most of the class time is spent acquiring data. With the use of automated data acquisition, the time required to obtain data is significantly reduced, and more time can be allocated for student experiment design and data analysis (Figure 2).

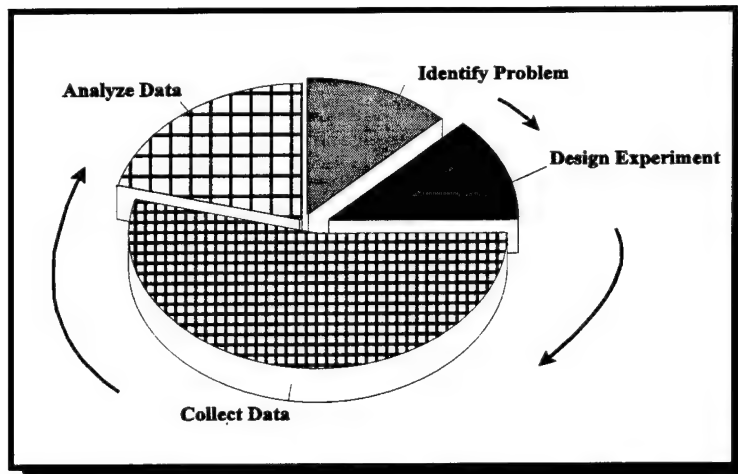


Figure 1. Time allocation for traditional experiments. Most of the laboratory time is spent on data collection, with little time left over for experiment design or data analysis.

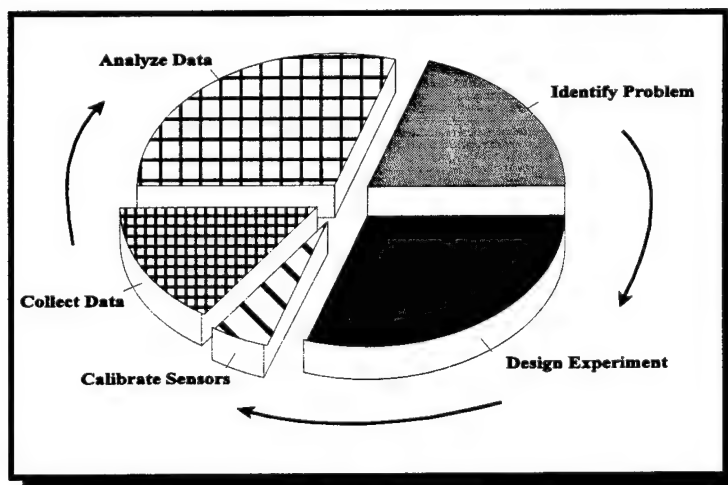


Figure 2. Time allocation for experiments using technology. Data collection time is reduced, and students may engage in higher levels of learning through experiment design and in-class data analysis.

Proper application of technology has also allowed the addition of final projects to MSU's laboratory curriculum. Students are presented with a brief description of a chemistry question, and then are required to design and implement an experiment to

measure a certain quantity and answer the question. In the winter of 1990, 650 introductory chemistry students were surveyed about their final laboratory projects. Seventy-five percent of the students surveyed believed that these projects were beneficial and should be continued.¹⁵ The final projects continue to be a part of MSU's introductory laboratory curriculum, and a survey of 257 laboratory students taken in the spring of 1995 concluded that 74 percent of the students believed the final projects were worthwhile. At other schools, independent projects are now being successfully implemented into upper-division undergraduate physical chemistry courses.¹⁶

Technology, Accessibility, and the Learning Model

The goal of this project is to employ technology to enable students to engage in higher levels of learning using situations similar to those found in final laboratory projects. Technology, however, will not be widely incorporated into college laboratories unless the obstacles mentioned previously can be overcome. To make technology accessible, the following conditions must be met:

- The technology must be affordable.
- It must be easy to use.
- It must be relevant to the chemistry content taught in lecture.
- Faculty must understand how to effectively employ the tools.

In this project the first two conditions are met via the development of new data acquisition hardware and software. The third condition, chemistry content relevance, is addressed using a teaching model aimed at higher levels of student learning. A capable experiment model using technology should address four pedagogical issues: chemistry

content, the process of science, relevant applications, and active student involvement.

Finally, all professors, teaching assistants, and laboratory managers must understand how the tools work.

In addition to being educationally sound, the teaching model must also be easy to implement. At McGill University in Montreal, Black and colleagues attempted to replace "cookbook" experiments with a completely unstructured approach to introductory chemistry laboratories.¹⁷ Students devised their own projects and then carried them out. The educational philosophy behind this sort of laboratory exercise is sound, but the logistical load placed on the prep room staff makes this particular approach impractical. Chemistry stock room costs and labor requirements must be considered when modifying laboratory curricula.

The technology proposed in this thesis is also designed to benefit the myriad of students taking introductory chemistry courses. Traditionally, classes were primarily 18- to 22-year-old men and women who had little experience outside their homes and hometowns. These students had spent three-fourths of their lives in school, so they could be convinced to learn a concept simply because they were told to do so. Today, a single chemistry section can contain students whose ages range from young adult to late middle-age.¹⁸ Many of these people have been out in the workforce, and they need to understand why learning chemistry is important, in both their present and future jobs, and in their everyday lives. Technology employed in the laboratory should also be relevant to the tools and instruments used in the modern workplace. The improvements proposed by this

project are directed at engaging both traditional and nontraditional students in the process of science.

Another barrier that must be surmounted is the negative attitudes of many teachers and students towards technology. Old teaching styles and expectations are not likely to work with new technology. Traditional teaching paradigms will have to be evaluated and possibly changed to enable higher learning using new technology. A shift in attitude must accompany new technology if that technology has any chance of being successfully used.

Project Description

This thesis presents ways to increase student critical thinking skills and learning levels through the effective use of technology, primarily for introductory chemistry laboratories. The project is divided into six areas:

- The Learning Model
- Improved Hardware
- Improved Software
- The Experiments
- Training and Instructional Philosophy
- Evaluation of Student Learning

The first goal of the project is to define higher level learning, and to apply a *learning model* that equates specific classroom actions to the thinking skills and levels of learning students achieve. To claim that students are learning at one level as opposed to another is difficult unless viewed in some form of context. In this project, the abstract concept of higher-level learning is applied in the context of Bloom's *Taxonomy of*

Educational Objectives. The taxonomy's learning levels form a backdrop for the activities made possible in student laboratories via proper use of new technology. The hardware, software, and experiments will enable students to learn at the higher levels described.

The *improved hardware* increases the use of technology by providing low-cost alternatives to existing equipment and enabling the measurement of physical quantities previously not possible. For example, control of the LabWorks interface has been expanded to include a hand-held Hewlett Packard HP 48 calculator, in addition to personal computer control. This set-up is ideal for laboratories that do not have the money or available space to use computers. In another improvement, low-cost turbidity measurements can now be made using the LabWorks colorimeter. Finally, a high-resolution temperature sensor gives a linear response to temperature changes as small as 0.001 Kelvin.

The *software improvements* section of this thesis describes how the World Wide Web is used as an administrative aid for teachers and as an information resource for students. Software also makes data acquisition technology "transparent" by providing a user-friendly interface. Context-sensitive help and an experiment design utility called EZ Program allow users to create experiment programs with merely a series of mouse clicks. Next, the computer as a simulation tool is explored, and the benefits of this application to chemistry education are described.

The *experiments* developed in this project apply the new hardware and software to chemistry concepts introduced in chemistry lecture courses. In addition to reinforcing

chemistry concepts, these experiments allow students to experience discovery-based learning. In this way, students are drawn into learning both chemistry content and the process of science in the laboratory. The experiments cover spectroscopy, colorimetry, turbidity measurements, dissolved gases, and environmental resources management.

Faculty training is another important part of this project. Without the support and understanding of professors and teaching assistants, technology can never be used to its full potential. The concept of paradigm shifting—the need for both students and teachers to adjust their expectations to match new technological tools—is explored. Many seminars and workshops have been conducted to educate college chemistry instructors about the benefits of properly used technology with the hope of changing their opinions on using technology. These workshops allow faculty to evaluate the effectiveness of teaching models that employ laboratory technology, and see first hand how the teaching model can meet their individual needs.

The last part of the project, *evaluation of learning*, validates the model by assessing student performance. Accurately measuring higher learning levels using traditional testing methods is a difficult prospect, but the exercises provide valuable information.

Statements of Original Work

This project requires creativity and input from many different sources. The tools developed here are a combination of original work of the author, collaborative efforts of the author and others, and sometimes original applications of tools developed by others.

Chapters describing the development of new hardware tools, software tools, and experiments include a section that distinguishes original work, collaborative efforts, and applications of existing tools.

Taken together, all parts of this project allow new technology to be successfully employed in introductory chemistry laboratories. The short-term benefit from this project is the technology—the hardware, software, and experiments. The long-term gain comes from the model that ties technology to a well-known and accepted classification of learning levels. Correct implementation and application of technology based on this model will benefit administrators, teachers, and most importantly, students.

CHAPTER 2

A TEACHING MODEL BASED ON BLOOM'S TAXONOMY

Defining and quantifying educational goals and standards is a difficult, but extremely important, aspect of education.¹⁹ Among the myriad systems of classifying teaching strategies, Bloom's *Taxonomy of Educational Objectives* has been an effective benchmark used to identify levels of learning. This chapter provides a synopsis of Bloom's taxonomy, examples of previous work using the taxonomy in science education, and a description of how the taxonomy is used to compare the tools developed in this project to those of traditional chemistry curricula.

Synopsis of Bloom's Taxonomy

Since its publication in 1956, the *Taxonomy of Educational Objectives* has profoundly influenced educators. The original taxonomy was broken into three distinct parts: cognitive, affective, and psychomotor. The cognitive domain concerns the process of learning and developing thinking skills. The affective and psychomotor domains refer to the appreciation of knowledge and the ability to perform hands-on tasks, respectively.²⁰ All work in this project relates to the cognitive domain.

Bloom's taxonomy (referred to in this thesis as "the taxonomy") presumes that students can learn information at different degrees of mastery. The taxonomy identifies six levels of learning, ranging from simple memorization to higher forms of learning such as synthesis and evaluation:

- Knowledge
- Comprehension
- Application
- Analysis
- Synthesis
- Evaluation

These levels build on each other. For example, a student who learns a concept at the comprehension level also understands at the knowledge level. Figure 3 illustrates the hierarchical relationship among the six levels.

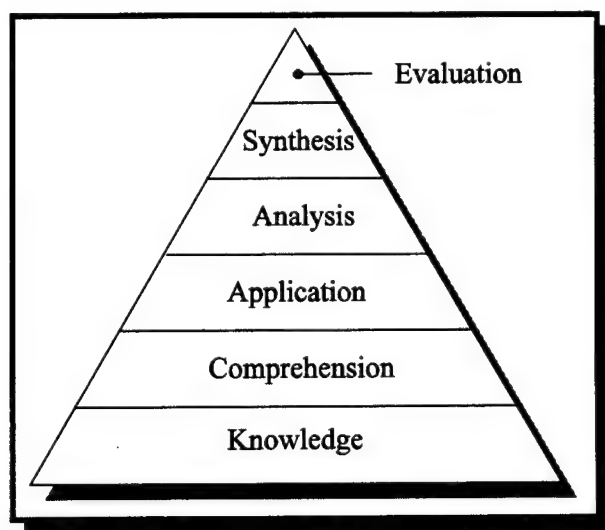
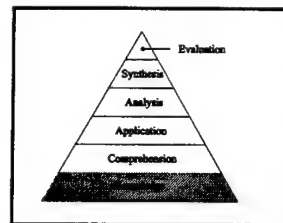
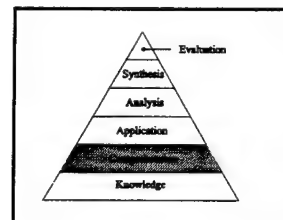


Figure 3. The six levels of learning according to Bloom's taxonomy. Evaluation requires the highest level of thought process.

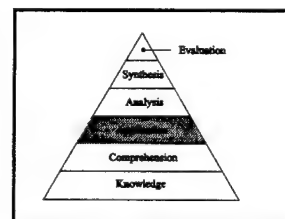
Knowledge is the simplest of the six classifications. It involves rote memorization of facts, without understanding any background or significance of the information memorized. As shown in Figure 3, this form of learning lays the foundation for the other higher levels of learning. This is also the level of learning most widely developed in schools because it is the easiest learning level to teach and evaluate. Chemistry lecture courses with large class sizes and testing with multiple-choice questions generally are aimed at the knowledge level of the taxonomy.



The next level of learning is *comprehension*. This level is also described as translation, interpretation, or extrapolation of ideas and concepts.²¹ More than rote memorization, comprehension requires a rudimentary understanding of the material being learned. Chemistry students show comprehension when they can identify chemical principles behind an in-class demonstration or explain the principles behind a traditional laboratory experiment. Students who ask "Why?" are learning at the comprehension level. Comprehension is evaluated on examinations using short-answer essay questions or multi-step numerical problems.



The *application* level of learning requires students to use a set of concepts to solve an ill-defined problem. The problem and the concepts required to solve the problem may at first seem unrelated. Students employ a higher level of thinking to connect the problem to the possible solution. An application-type chemistry problem



requires students to take an abstract chemical concept and use it to solve a meaningful, real-world problem. At this level of learning, students begin to internalize knowledge-level mastery of information. Traditional chemistry laboratory experiments allow students to learn chemistry concepts at the comprehension and application levels by making measurements of physical phenomena and converting the raw data to useful information. In the laboratory, students are presented with a problem, and they work toward its solution. *How* they go about solving that problem determines the level of learning they experience. In Figure 4, the act of acquiring and organizing data engages students at the application level of Bloom's taxonomy. The type of problem presented to students is very important. The problem must motivate students by being relevant to their lives, and it must require high-level thought processes to be solved successfully.

Traditional chemistry experiments do not, however, allow students to experience the last three levels of learning: analysis, synthesis, and evaluation. Students must design their own experiments and evaluate the results of these choices to master the concepts at these levels of learning. Teaching at these learning levels also demands the most innovative teaching methods from the instructor. Technology can provide one tool for accessing these higher learning levels.

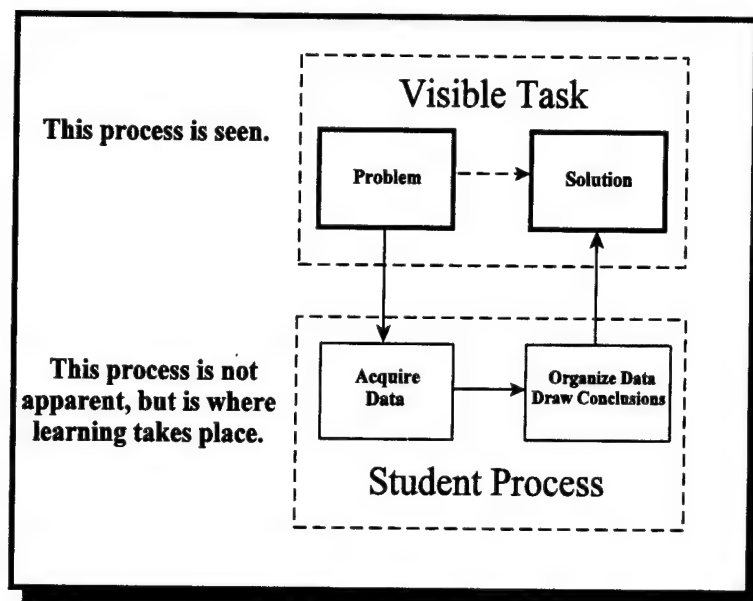
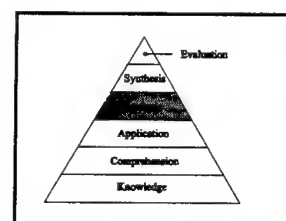
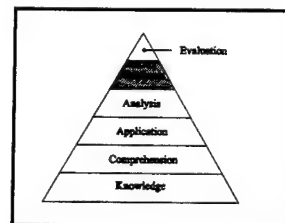


Figure 4. Laboratory actions involving comprehension and application levels of learning. The choice of problem defines the visible task. Experiments can be designed so that solving the problem requires that students use progressively higher level thought processes.

Analysis involves taking a concept apart and working with the individual components separately. A chemistry-related example of this would be to present students with the general concept of equilibrium, and have them work with this concept in terms of acid dissociation equilibria, solubility equilibria, and even thermodynamic equilibria. After examining the separate parts, the original concept as a whole then becomes clearer. Analysis can be combined with evaluation, thus forming "critical analysis."²² Critical analysis is the type of educational activity that is the centerpiece of curricular reform sponsored by the National Science Foundation.²³



The next level of learning, *synthesis*, is seemingly the opposite of analysis. While learning at this level does involve combining apparently unrelated concepts into a unified whole, students are encouraged to express a large degree of creativity.



The product of synthesis comes from within the students, and is not merely a reiteration of concepts from the instructor. This learning is creative, but not completely free-form, as boundaries are given by the stated problem.²⁴ Mastering situations in which students solve real-world problems requires that the students synthesize knowledge they have acquired throughout the course.

The chemistry projects discussed in Chapter 1 and the discovery-based experiments developed as part of this project enable students to learn chemistry concepts at the analysis and synthesis levels. When student experiment design is added to the flow chart in Figure 4, the laboratory experience progresses to the analysis and synthesis levels of learning. Figure 5 shows the laboratory actions students perform to learn at the analysis and synthesis levels of the taxonomy. The visible task still takes students from the problem to the solution, but the process is more complicated, demanding higher-level thought processes than are needed to solve a simpler problem.

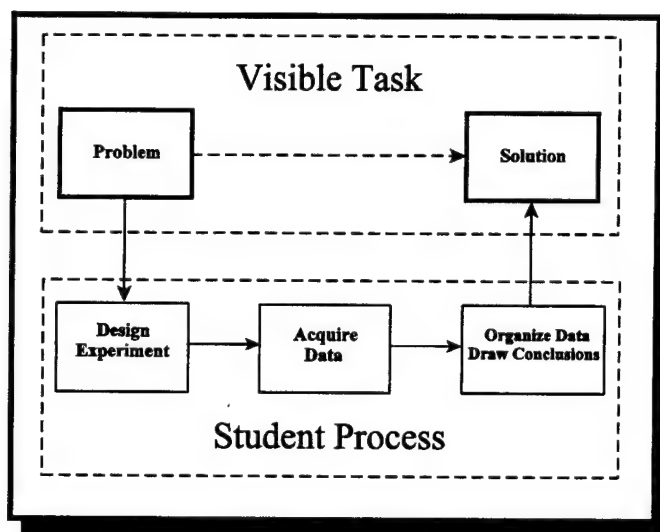
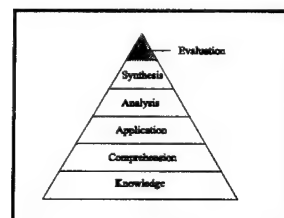


Figure 5. Laboratory actions involving analysis and synthesis levels of learning. Addition of an experiment design component involves students in synthesis-level actions.

Evaluation is the pinnacle of Bloom's taxonomy hierarchy. It is the highest level of learning, according to the taxonomy, and it is also the level of learning that is practiced the least in schools. Evaluation prompts students to consider the effectiveness of their own efforts; students are challenged not merely to solve a problem, but to determine how they can reach the solution more effectively. The laboratory actions required for evaluation include the actions from Figure 5, with the addition of self-assessment and a feedback loop for design improvement (Figure 6).



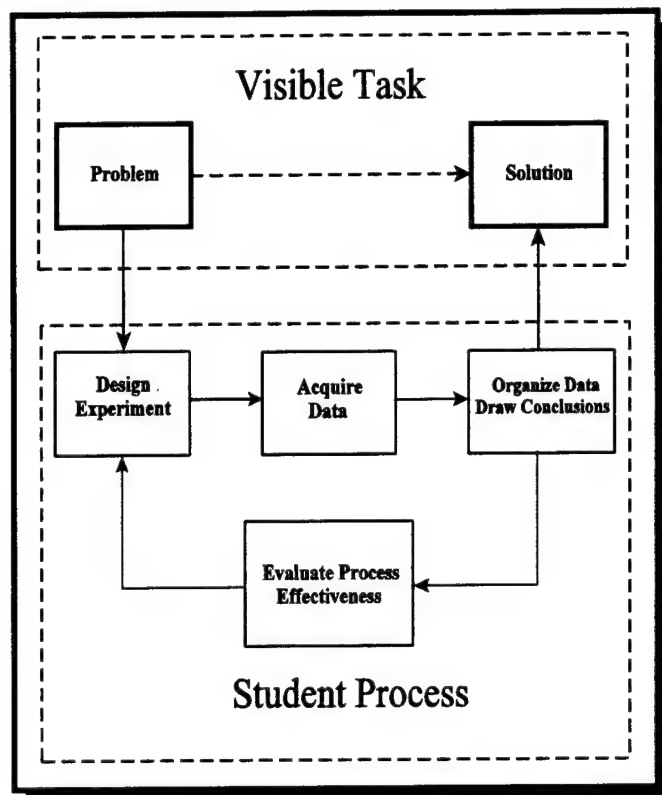


Figure 6. Evaluation—the highest level of learning in Bloom's taxonomy—requires students to examine the results of their experiments and modify their experiment designs.

When practiced in the chemistry laboratory, evaluation exercises do far more than reinforce students' chemistry knowledge. Work at the evaluation learning level also gives students the valuable opportunity to practice critical thinking skills. Experience in solving loosely defined problems using evaluation skills will benefit students in their upper-division course work as well as in their jobs after graduation.

Previous Work Involving Science and Bloom's Taxonomy

The taxonomy has been widely applied to curriculum evaluation, especially to humanities courses, such as social studies and psychology.²⁵ Comparatively, its application to science courses has been relatively limited. At the K-12 science levels, the taxonomy has been used to assess middle school science textbooks²⁶ and elementary school science research programs.²⁷ The taxonomy has also been successfully applied to college physics courses.^{28,29}

The use of the taxonomy to improve chemistry teaching is even rarer than its application to other science curricula. The last studies relating the taxonomy to chemistry concerned high school chemistry courses and were published in 1974³⁰ and 1977.³¹ These studies evaluated standardized test questions and cooperative learning exercises, but did not address learning in the chemistry laboratory.

Because personal computers were not widely used until the mid-1980s, none of the published studies have used the taxonomy to address the effects of computer technology on students' abilities to learn chemistry. This project, then, could be the first study to relate the effectiveness of new technology on learning using Bloom's *Taxonomy of Educational Objectives*.

Technology and Bloom's Taxonomy

To develop the skills needed to work at the higher levels of learning in the taxonomy, students must be placed in situations that require these skills. Students must

also be provided with tools that will allow them to work at these levels. The new hardware and software described and developed in this thesis are tools students will use, and the experiments will place students in the higher-level learning environments.

The goal of this project is to increase the opportunities students have to work at higher levels of learning as defined by Bloom's taxonomy. The hardware, software, and experiments developed in this project make possible the laboratory actions that result in student involvement at higher learning levels. Figure 7 demonstrates the relationship between the tools, student actions, and the final goal of higher-level learning.

The experiments in this project create the learning situations. To successfully complete the experiments, students must use thinking skills in the upper levels of Bloom's taxonomy. While direct evaluation of the higher learning levels is difficult, successful completion of the experiments can indicate that higher-level learning was achieved. Specific laboratory actions and the corresponding learning levels are described in detail in Chapters 7-10 of this thesis.

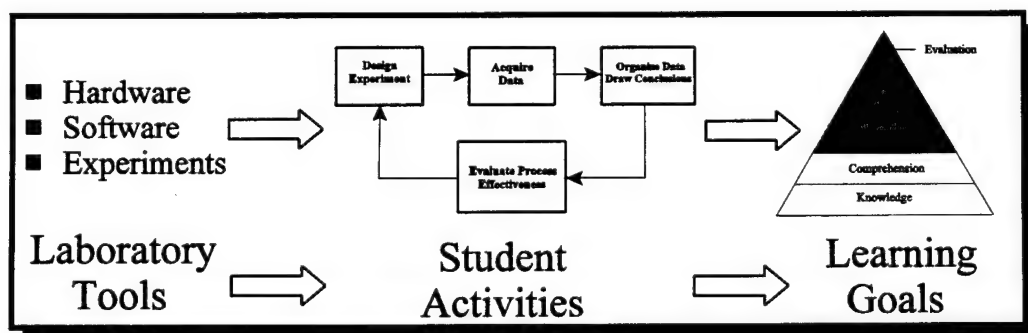


Figure 7. The experiment is the link between the tools developed in this project, the actions students perform, and the final goal of higher-level learning.
Technology enables student actions which result in higher levels of learning.

Conclusions

Studies in this project and others show that the development of lower learning levels (knowledge, comprehension, and application) of the taxonomy do not suffer with the inclusion of activities that promote the upper levels (analysis, synthesis, and evaluation).³² While direct evaluation of the upper levels of learning is difficult to achieve, the idea of promoting these learning levels while maintaining lower-level learning makes this project worthwhile.

Time and budget constraints imposed on colleges and universities often make learning at the upper three levels of the taxonomy impractical. Appropriate application of technology can help overcome these barriers, allowing innovative teaching strategies to enhance students' learning experience.

The basic premises of this project are (1) that correctly designed experiments will engage students in upper levels of learning, and (2) technology makes the experiments possible. Short-term benefits are realized directly from the technology and the experiments applied in this project. Long-term benefits of this project will come from the model of employing technology to draw students into activities which promote analysis, synthesis, and evaluation levels of learning.

CHAPTER 3

HARDWARE INNOVATIONS

As stated in Chapters 1 and 2, the goal of this project is to develop hardware, software, and experiments that will enable students to develop advanced learning skills identified by Bloom's taxonomy. The hardware developed for this project is designed to provide low-cost tools that students can use to measure a wider range of physical properties than was previously possible. This hardware enables students to perform experiments that result in learning at the upper levels of Bloom's taxonomy. Figure 8 shows the relationship between the hardware and the high-level learning goal.

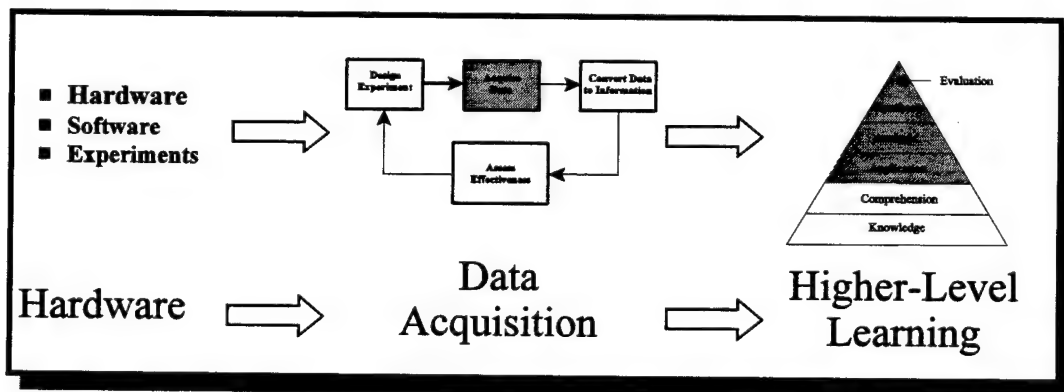


Figure 8. How hardware tools enable higher levels of learning. Improved hardware enables student actions that result in the higher levels.

Creativity is a key element in facilitating learning in the upper taxonomy levels. Students can be provided with a versatile array of research tools which provide opportunity for creativity, but which also keep equipment costs reasonable. This chapter describes the LabWorks II interface, and how this tool is used to place students in advanced learning situations. Many of the experiments outlined in this thesis employ the LabWorks II interface. This chapter also introduces and develops two new sensor applications: a high-resolution temperature measuring device and an apparatus capable of making low-cost turbidity measurements.

Statement of Original Work

The LabWorks II interface is part of the data acquisition systems developed in this project. Improvements were made to the LabWorks interface before this project started. Those improvements, specifically the inclusion of onboard RAM and CPU, make possible the development of hardware and software that are part of this project. Original work in this chapter includes adapting the Kelvin sensor for use with the LabWorks II interface and development of the LabWorks turbidimeter for use in introductory experiments.

The LabWorks II Interface

The LabWorks II interface is the latest in a series of computer-controlled data acquisition systems invented at Montana State University, then developed further by SCI Technologies.³³ The interface was designed to save laboratory space and reduce

equipment costs by replacing many single-use instruments with a multi-purpose data acquisition system. See Figure 9. Operational amplifiers and analog-to-digital converters (ADCs) are contained in the interface itself, allowing simple and inexpensive sensors to be used with the interface.

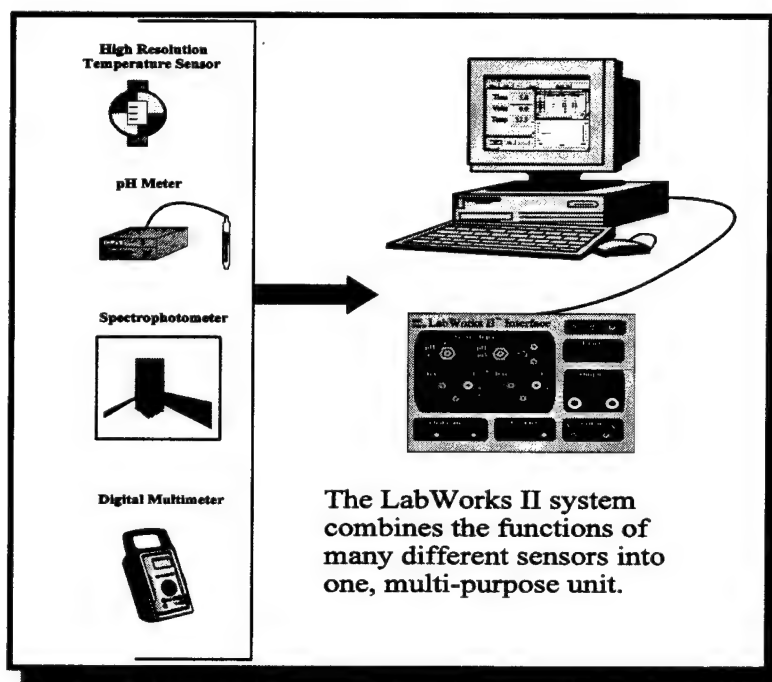


Figure 9. The LabWorks interface combines the functions of many different types of sensors in a single measurement system. The result saves time and money.

MSU Interface

The first widely used interface was the MSU interface.³⁴ It incorporated a 13-bit ADC and an 8-bit digital-to-analog converter (DAC). Four sets of external banana jacks on the front of the interface allowed for two voltage and two current inputs, while two BNC connectors accepted pH or millivolt probe inputs. Two pushbutton and two toggle

switches were used for experiment control, and four sets of output jacks powered light sources. A helpful feature of this interface was the addition of light-emitting diodes (LEDs) to allow users to see which inputs were being used. Figure 10 shows the layout of the front of this interface.

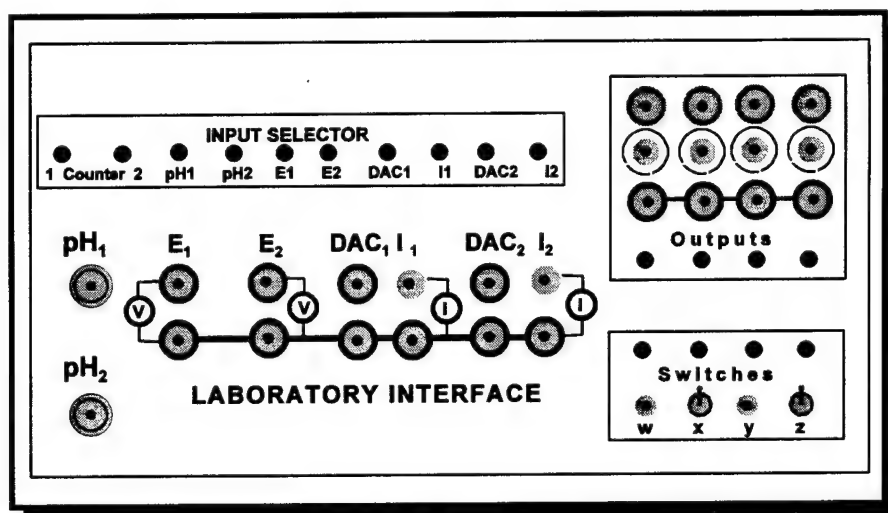


Figure 10. Front panel of the MSU interface.

Inputs for digital inputs, such as photogates and counters were located at the rear panel of the interface. There was also a 9-pin accessory port, as well as the connector that attached to the controlling computer. A 25-pin cable connected the interface to an 8-bit parallel card (Figure 11) that plugged into a personal computer's expansion slot. Figure 12 shows the layout of the MSU interface's rear panel.

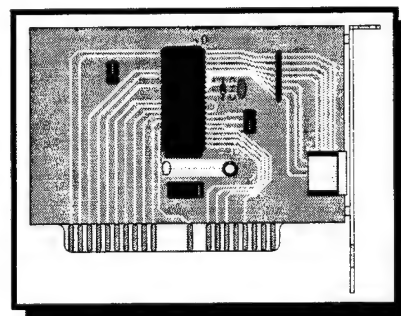


Figure 11. Parallel input card for MSU and LabWorks interfaces.

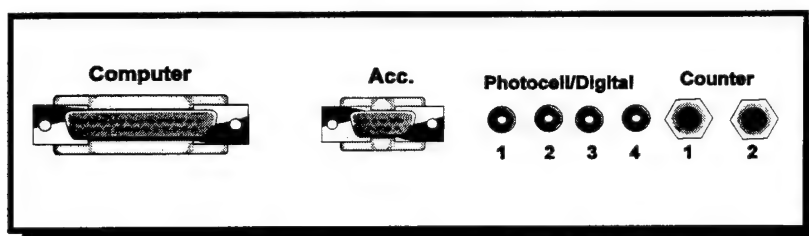


Figure 12. Rear panel of the MSU interface. Photocell and counter inputs were plugged into this panel.

Because electrical current-producing sensors incorporate such a wide range of outputs, the MSU interface used an autoranging current input. At very small current inputs the software adjusted the interface operational amplifier to read at a very high 0.6 nanoampere resolution.³⁵ Higher current ranges were automatically scaled down to give a maximum current reading limit of ± 2.5 milliamperes.

LabWorks Interface

The next generation of the interface—renamed LabWorks—incorporated many improvements to its original design. The size of the interface was reduced, and more input controls were placed on the front panel for easier access. Only the computer connection, which remained the same, and a 15-pin accessory port were located on the rear panel. A few of the lesser-used control switches and outputs were removed, and feedback LEDs were relocated next to the sensor inputs. While the exterior of the LabWorks interface looked very different from the original MSU interface, many of the internal components were similar. Figure 13 shows the front and rear panels of the LabWorks interface.

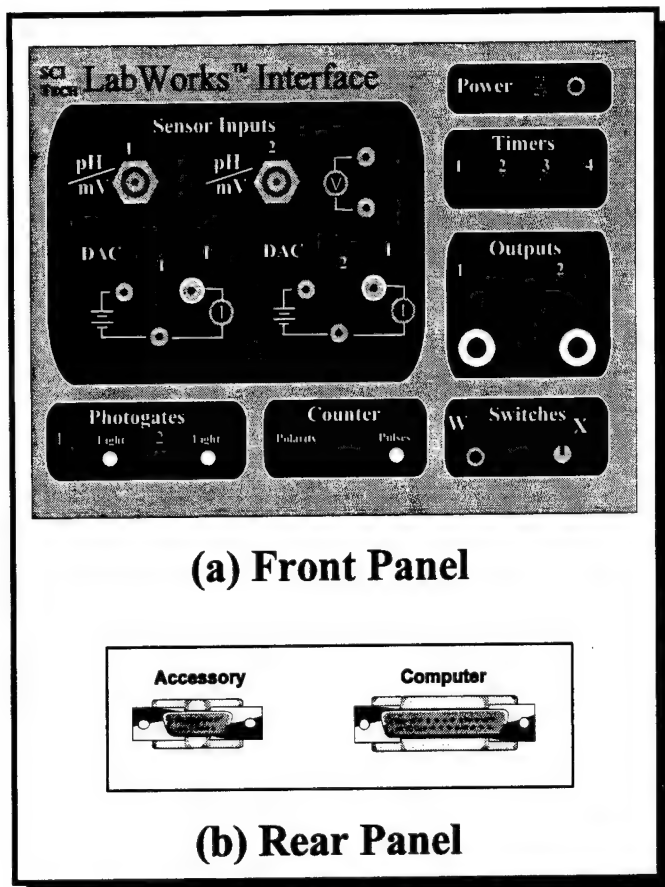


Figure 13. Front and rear panels of the LabWorks interface. In an improvement over the MSU interface, only the accessory port and computer cable plugged into the rear panel.

The MSU interface included software that worked only with IBM-compatible and Apple II computers. SCI Technologies produced software that allowed the LabWorks interface to communicate with Macintosh computers. Hardware incompatibilities between Macintosh and DOS computers prevented the parallel input card (Figure 11) from being installed in Macintosh computers. To overcome this problem, SCI wrote serial communication routines in their Macintosh software and incorporated a hardware

parallel-to-serial adapter to allow Macintosh computers to control the LabWorks interface.

LabWorks II

The third and latest interface version is LabWorks II. The front of the new interface looks very similar to its predecessor (Figure 14a), but LabWorks II incorporates many different internal changes. For communications, the 25-pin parallel interface and proprietary card have been replaced by a 9-pin serial connection. The change in communication protocol eliminates the need to install input cards in DOS computers or use parallel-to-serial adapters with Macintosh computers.

Another change to LabWorks II was the inclusion of a 80C51 microprocessor and 32 kilobytes of on-board random access memory (RAM). The on-board microprocessor allows many interface functions to be performed internally, rather than relying on commands from the host computer. For example, the autoranging current amplifier no longer requires software commands to function. The different current measurement ranges and resolutions that the LabWorks II interface are capable of reading are listed in Table 1.

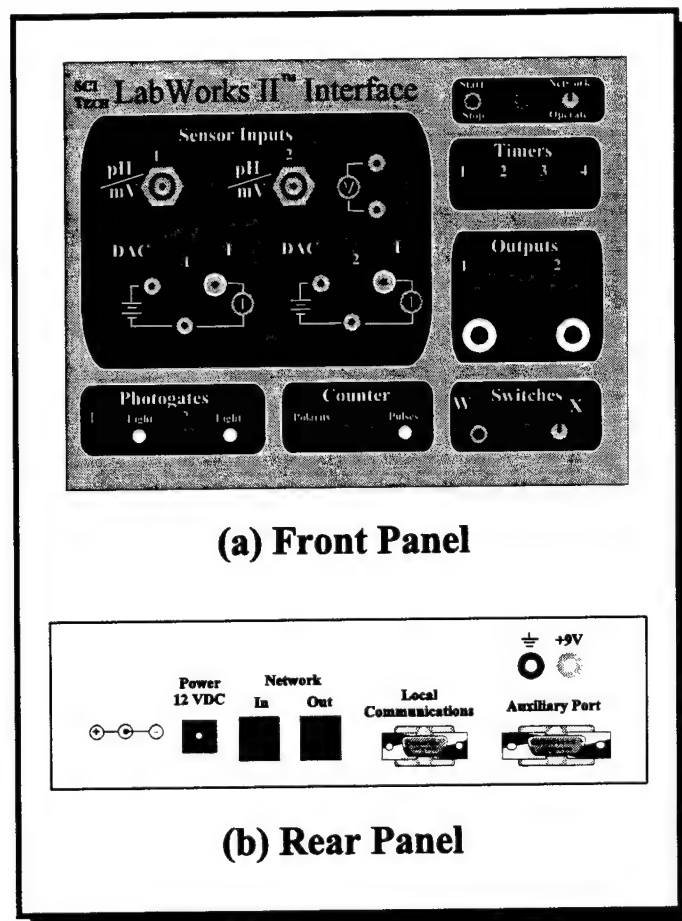


Figure 14. Front and rear panels of the LabWorks II interface.

| Full Scale Current (μA) | Resolution (μA) |
|--------------------------------------|------------------------------|
| 2048 | ± 1 |
| 204.8 | ± 0.1 |
| 20.48 | ± 0.01 |
| 2.048 | ± 0.001 |

Table 1. Autoranging current ranges and resolutions useable by the LabWorks II interface.

Figure 14b shows the rear panel of the LabWorks II interface. The most significant addition to the rear panel is the inclusion of input and output network connections. LabWorks II has the hardware capability to build a network of interfaces all connected to a single host computer. The host computer can download data acquisition programs to each interface in the network chain so that the interfaces can obtain and store experimental data independent of each other. Experimental data can then be uploaded to the host computer for display and analysis.

The data acquisition hardware and software in this project work exclusively with the LabWorks II interface. Internal improvements made in this latest interface make many of the new hardware and software tools developed in this project possible.

High-Resolution Temperature Measurements

Most temperature measurements taken with the LabWorks system use a temperature sensitive resistor, or thermistor. Thermistors have a negative temperature coefficient, which means that their resistance decreases as temperature goes up. Figure 15 shows that these devices exhibit a logarithmic response to variations in temperature.³⁶ The response curve indicates that thermistors are more sensitive to temperature changes at low temperatures and less sensitive at high temperatures. The logarithmic response of these sensors also requires complex calibration routines.³⁷ Kelvin sensors, on the other hand, are designed to exhibit a linear response to temperature changes. These devices use an input voltage in the range of 4 to 30 volts DC, and produce a current equal to the

absolute temperature. For example, at a temperature of 273K, this sensor produces a current of 273 μA .

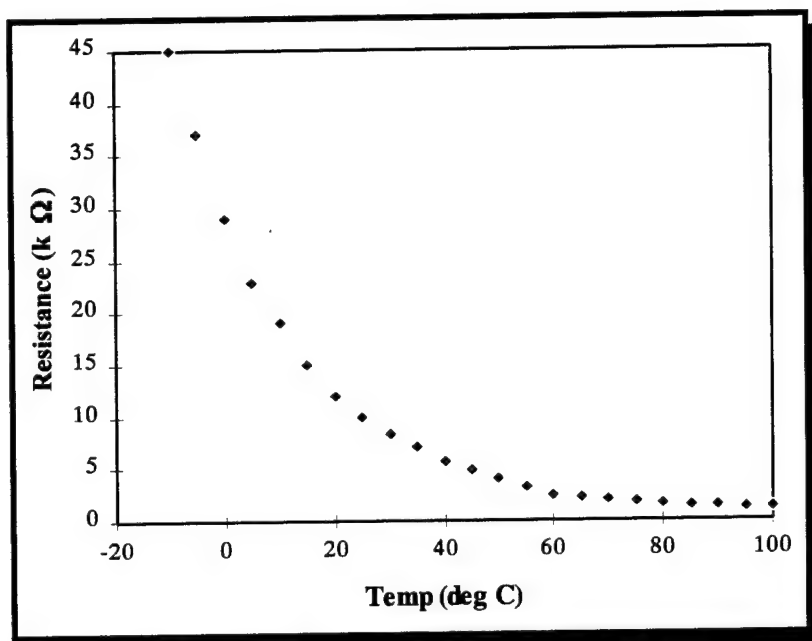


Figure 15. Thermistor temperature sensitivity. This sensor is sensitive at low temperatures and loses its sensitivity as the temperature increases.

The Amend research group has combined the Kelvin sensor, a 1,000 ohm resistor, and the LabWorks II interface to produce differential temperature readings with a theoretical resolution of 0.001 K.³⁸ The LabWorks II interface's DAC applies a reverse bias voltage to the Kelvin sensor. This voltage forces the interface's current-reading amplifier to use its highest setting, allowing the Kelvin sensor to detect 0.001 K temperature changes within ± 2.048 K from the calibration point.

When used with the LabWorks interface and DOS software, Kelvin sensors measure temperature changes relative to a predefined calibrated point. These sensors

range in price from \$17 to as low as \$3, making them a low-cost alternative to thermistors as temperature sensors.

Using the LabWorks Interface to Measure Turbidity

The Importance of Measuring Turbidity

Many recent news stories have been devoted to the subject of clean water. In 1996, Montana's Initiative 122 clean water project evoked both strong support and strong opposition. This hotly debated political topic's roots come from science. Specifically, from questions such as: (1) How do people know that their water is polluted in the first place? and, (2) How will they know when their water is clean? Turbidimetry and nephelometry are two common techniques used to measure and quantify water quality.

Turbidity measurements have a wide range of applications, both commercial and scientific. In addition to drinking water quality, turbidimetry can determine the purity of other liquids, such as organic solvents. Industry also uses turbidity measurements. For example, turbidimeters measure the amount of iron contamination in pulp and paper manufacturing. Many food production facilities, such as beverage and cheese manufacturers, use turbidimetry to determine bacterial growth and filtration efficiency.

Because turbidimetry is an important industrial and ecological process, its concepts should be taught in Environmental and General Chemistry laboratory courses. However, few courses teach this concept because the equipment needed to obtain accurate turbidity measurements is too expensive to use in general chemistry laboratories. A cost-effective alternative is the LabWorks interface and wood block colorimeter. This

section describes the basic principles underlying turbidimetry and nephelometry, and illustrates the layouts for existing types of turbidimeters. The LabWorks-based apparatus is then described and compared to present designs.

Basic Turbidity Measuring Principles

Turbidity measurements determine water quality based on the amount of light that scatters off particles suspended in solution. Impurities in solution (silt, clay, or living organisms) cause more light to scatter and less light to shine straight through. Turbidity is defined as the “expression of the optical property that causes light to be scattered and absorbed rather than transmitted in straight lines through a sample.”³⁹ A simpler definition is that turbidity is the opposite of clarity.⁴⁰

Measuring the turbidity of a solution is a rather complicated process. One cannot simply insert a vial into a machine and “measure turbidity.” The amount of light scattered by a sample depends on many factors, such as the size and shape of particles in the sample, the wavelength of light being scattered, and refractive index of the particles relative to the solvent’s refractive index.⁴¹

Because different types of suspended particles can have varied scattering properties, it is necessary to calibrate turbidimeters, then compare unknown samples to standard readings. Scattered light varies with particle concentration in a relationship similar to Beer’s Law.⁴² Turbidity measurements can then be accurately made by generating a calibration curve using known standards, and fitting the reading of an unknown sample (of the same substance) to this calibration curve.

The concentration range in which Beer's Law applies depends on the sample being measured, as well as the instrument taking the readings. As a general rule, a larger linear dynamic range requires a more complicated instrument. Different turbidity instrument designs are described in the next section.

Devices for Measuring Turbidity

Early turbidity measuring devices used a glass cylinder and a candle flame. The person measuring turbidity recorded the depth of liquid required to obscure the candle flame into a uniform glow. This type of turbidimeter, called the Jackson candle turbidimeter (Figure 16), suffered from severe limitations. The quality of the readings depended greatly on the skill (and eyesight) of the person making measurements. This method was also impractical for measuring very small amounts of impurities.

Another method for measuring light-scattering impurities is called nephelometry. This technique involves shining a light source on the sample and placing a light detector 90° to the light source. Impurities in the sample cause source light to scatter and strike the detector. Figure 17 illustrates a simple nephelometer.

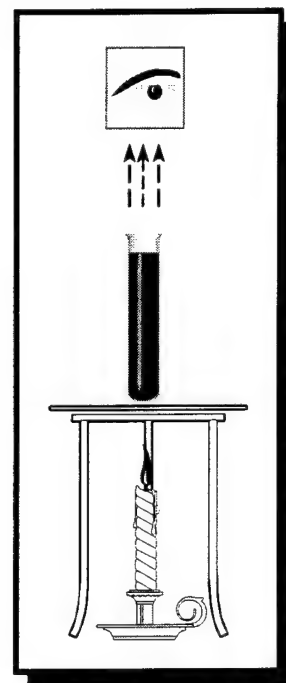


Figure 16. Jackson candle turbidimeter

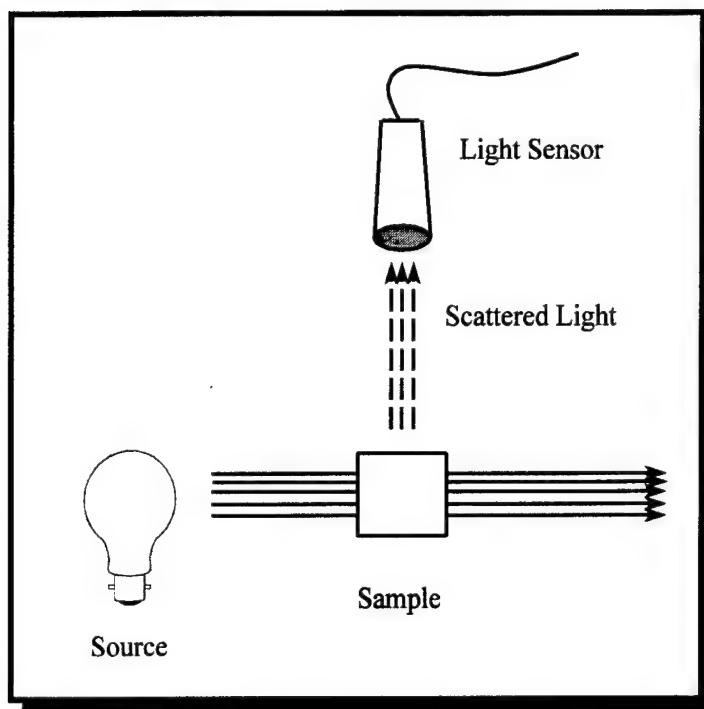


Figure 17. Simple nephelometer. The light sensor at 90 degrees from the light source measures scattered light.

In simple nephelometry, light scatters in all directions, not just at right angles to the light source. The amount of scattered light that reaches the detector is just a fraction of the total scattered light, making this a challenging technique for measuring very small concentrations. A more sensitive (and more complicated) design would use more light sensors to obtain more signal.

Ratio nephelometers use one or more additional light sensors to measure the ratio of scattered light to transmitted light. Figure 18a shows a ratio nephelometer with an additional light sensor that measures transmitted light.⁴³ This device increases the linear

range of the simple nephelometer by comparing the light that is transmitted through the sample to scattered light.

The ratio nephelometer in Figure 18b employs a third sensor not in line with the source to collect forward scattered light.⁴⁴ The data processing for this instrument is highly involved, but this design is the best for measuring extremely small analyte concentrations. Note that this instrument uses a blackened mirror to minimize overloading the transmitted light detector.

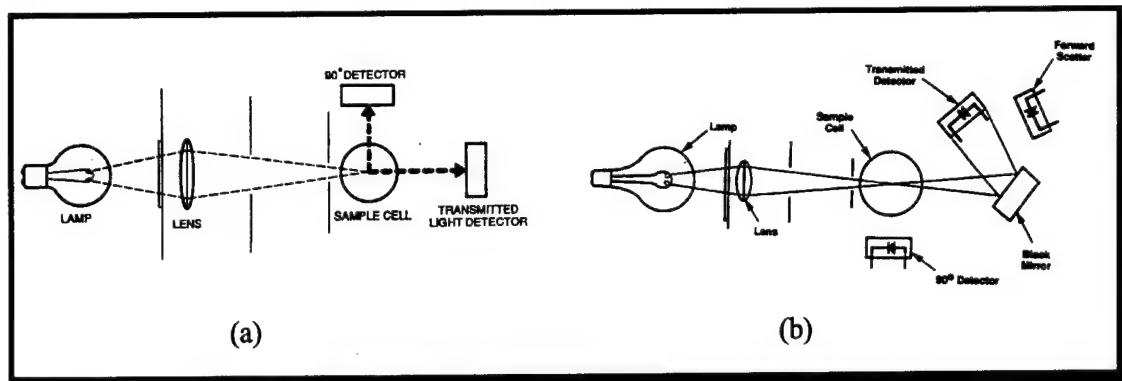


Figure 18. Two types of ratio nephelometers.

In some cases, such as waste water management, it is impractical to collect and measure individual water samples. These situations call for a turbidimeter that measures a constant flow of water. Constant-flow surface scatter turbidimeters can measure light scattered from a sample as it flows through a transparent pipe. These turbidimeters can be placed at various points along a waste water stream to measure the effectiveness of clean-up strategies and techniques. Figure 19 shows an example of this type of turbidimeter.⁴⁵

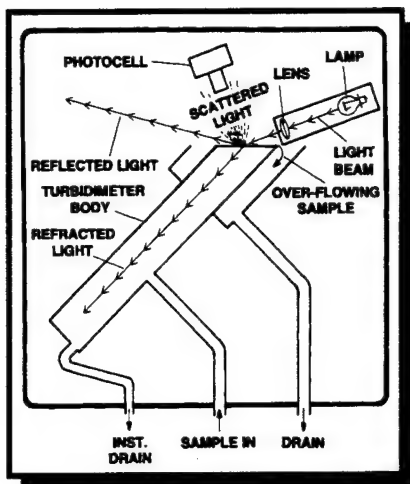


Figure 19. Constant-flow, surface scatter turbidimeter.

Turbidimeter and Nephelometer Components

The most important elements of any turbidity measuring device are the light source, sample holder and optics, and light sensor. As with any spectrometer, the operator wants to use the best components available while avoiding prohibitively high costs.

Light Sources. Lower-energy forms of radiation such as infrared and red light sources are preferred for turbidity and nephelometry measurements. These sources produce much better scattering than sources such as blue or ultraviolet light. The higher energy sources may electronically excite the samples, possibly causing fluorescence or phosphorescence, introducing significant errors in turbidity measurements. The only desired interaction between the light source and the sample is that the sample deflects, or scatters, the source light.

Several common light sources are used for turbidity measurements. The Jackson turbidimeter uses a candle as a light source. Certainly this is an inexpensive source, but it lacks the reproducibility necessary for serious quantitative analysis. Heat from the candle flame can also introduce error into the readings. Many commercial instruments use a tungsten-filament lamp as a source. This type of light source is inexpensive and reliable, but it requires a well-regulated power supply to make reproducible readings. It is a polychromatic source whose output ranges from about 400 nm to well into the infrared region. Some turbidity measurements may require a narrower band illumination source than a tungsten-filament lamp. Two types of narrow-band sources used for turbidity measurements are LEDs and lasers. LEDs are very inexpensive to use, but lasers provide a greater amount of illumination at a single wavelength.

There is no single rule that governs which light source to use. Every measurement and sample type has a different set of requirements. The correct light source depends on the sample concentration range, the chemical nature of the sample, and on budget constraints.

Optics and Sample Cells. The optics of turbidimeters and nephelometers are fairly simple, being limited to focusing the source light on the sample, or reflecting light to the detector. Figures 18a and 18b show typical uses of optical elements in turbidimeters and nephelometers. Sample cells for turbidity measurement must be scratch resistant, as scratches on the glass scatter large amounts of light, obscuring light scattered from the sample. Some cuvettes used for spectroscopy only allow light to pass

straight through the sample. Sample cells for turbidity measurements must also allow scattered light to pass through at right angles to the source light, and sometimes in all directions. Examine Figures 18a and 18b. To account for different scattering properties of different individual sample cells, the same cell should be used for all measurements and should be oriented the same way.

Light Detectors. The most common light detectors used in turbidimeters and nephelometers are the photomultiplier tube (PMT), silicon photodiode (or phototransistor), and cadmium sulfide (CdS) photocell. Photomultiplier tubes give the best response for shorter wavelengths of light. A PMT combined with a tungsten filament source is a good combination for measuring turbidity caused by comparatively small suspended particles.

Photodiodes and phototransistors are very inexpensive and are the best choices for a turbidimeter in a student lab. These solid-state light sensors have the greatest sensitivity for longer wavelengths of light. A turbidimeter or nephelometer that uses an infrared LED source and a photodiode detector would measure turbidity caused by larger particles very well. Figure 20 shows the spectral response for photodiodes and phototransistors. The CdS cell has a spectral response that lies between the PMT and the photodiode.

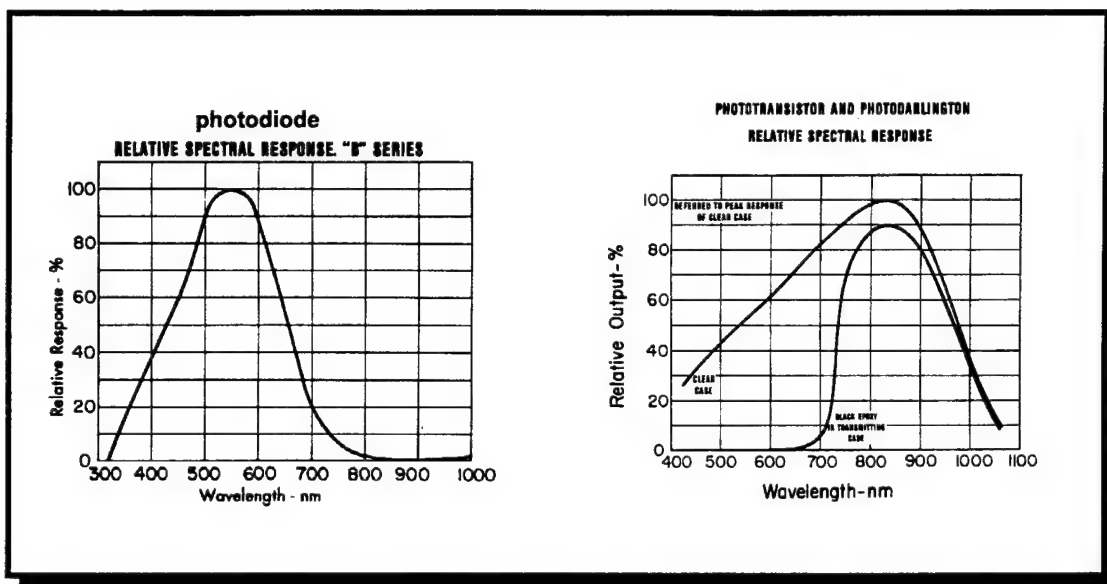


Figure 20. Relative spectral response for the photodiode and phototransistor. (Adapted from Vactec Optoelectronics Catalog.)

Obstacles to Effective Turbidity Measurements

The greatest hindrance to effectively measuring turbidity is noise caused by light that strikes the detector but is not caused by sample scattering. This type of light is called *stray light*.⁴⁶ Stray light comes from the source focusing system, the sample holder, reflections from the sample chamber, or even from outside light leaking into the sample chamber. Figure 21 depicts the different sources of stray light. The best way to account for stray light is to calibrate the nephelometer by measuring a blank, which is a sample holder containing solvent without analyte present. Since most turbidity applications measure particles suspended in water, distilled or deionized water is used for this calibration. The effects of scratches on the surface of the sample cell can be minimized by applying a thin film of silicon oil to the cell surface.⁴⁷ The oil must not be overused,

and it must have the same refractive index as the sample cell material to minimize light loss at the oil/glass interface.

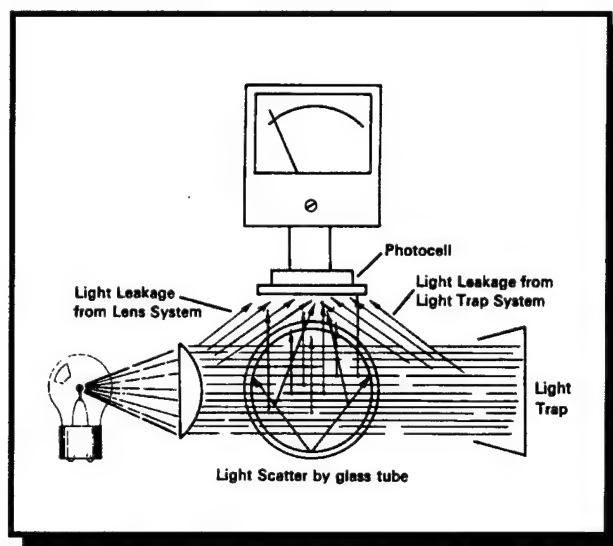


Figure 21. Causes of stray light.

Inaccurate turbidity readings may also be caused by gas bubbles in the sample. These bubbles are caused by nitrogen, oxygen, and carbon dioxide from air that comes out of solution. Eliminating bubbles from a solution is called *degassing*. A sample can be degassed by (1) applying a partial vacuum, (2) adding a surfactant, (3) using an ultrasonic bath, or (4) heating the sample. Applying a partial vacuum is the method that least disturbs the sample. Adding extra chemicals (such as a surfactant), applying heat, or ultrasonic agitation could change the light-scattering properties of the particles suspended in solution and affect turbidity readings more than the presence of gas bubbles.

Significant errors also occur in turbidity measurement if the sample absorbs, rather than scatters, light. When using a ratio nephelometer, absorption will give an

unreliable reading from the transmission sensor. Any photo luminescence that occurs will be indistinguishable from scattered light detected by the 90° sensor. To prevent sample absorption of light, the excitation wavelengths must be prevented from interacting with the sample. This can be accomplished by either using filters or narrow-band emission sources, such a colored LED or laser. It is also important to know which wavelengths the sample is absorbing. To determine this, the sample must be scanned using a UV-Visible and IR spectrometer.

A linear response for turbidity measurements can be achieved over a wide range of particle concentrations using the ratio turbidity method. However, in solutions containing very large concentrations of particulate matter, the scattered light can be rescattered many times, giving a false low reading in the 90° light sensor. When this occurs, the sensor goes “blind,” and the sensor response is no longer linearly related to concentration.⁴⁸ Calibrating the turbidimeter using values both above and below the estimated sample concentration will ensure that the sensor response stays in the linear region. If the sensor goes blind, the sample can be diluted until it gives a linear response.

Applying These Principles to the LabWorks Turbidimeter

Turbidity measurements can be made using the LabWorks wood block colorimeter. Light sensors can be placed in a direct line and at 90° to the light source. Figure 22 shows both a side view and a top view of this set-up. This apparatus uses ratio nephelometry principles similar to the device shown in Figure 18a.

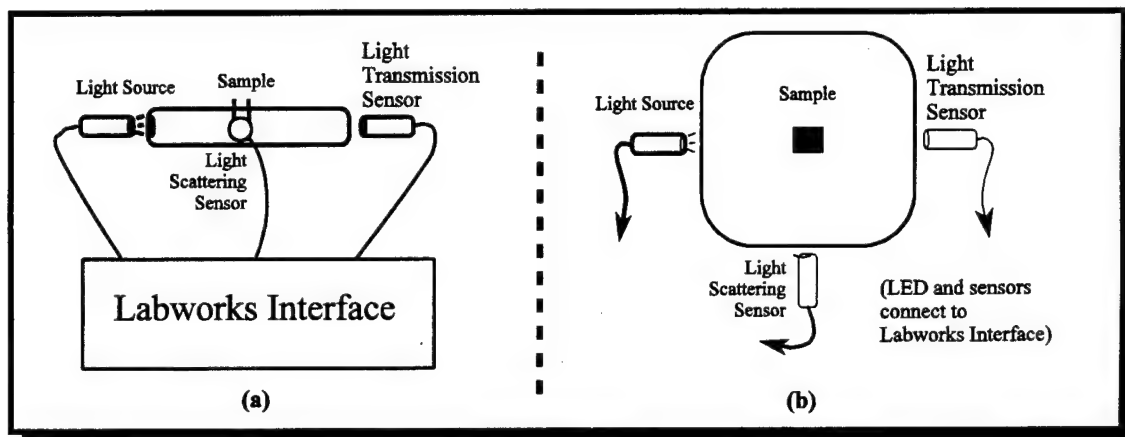


Figure 22. Side view (a) and top view (b) of LabWorks turbidimeter.

The light source can be a small incandescent bulb, a colored LED, or even a handheld diode laser pointer. To find the best light source for LabWorks turbidity measurements, a turbidimeter was set up like the one in Figure 22, and a formazin turbidity standard was measured using different light sources. The standard was obtained from Hach Co. and rated at 4,000 nephelometric turbidity units (NTU). An NTU is equivalent to 1 part per million suspended solid. 4,000 NTU is much higher than we would actually measure when performing turbidity experiments. For the purpose of finding the best light source, a highly concentrated solution was used. Identical phototransistors were used to detect transmitted and scattered light for each measurement. The results are summarized in Table 2. According to this data, the infrared LED is by far the best light source for LabWorks turbidity measurements.

Scattered and transmitted light can be measured using a photodiode, phototransistor, or photodarlington, depending on the amount of light being scattered and

| Source | Color | Wavelength (nm) | Scattered Signal (μA) | Transmitted Signal (μA) |
|-------------------|-----------|-----------------|------------------------------------|--------------------------------------|
| Incandescent Bulb | Broadband | — | 0.2563 | 4.7699 |
| LED | Red | 635 | 0.0439 | 0.1180 |
| LED | IR | 880 | 2.2869 | 20.2865 |

(Amber, Green, and Blue LEDs were measured, but these sources did not produce a readable signal.)

Table 2. Responses of different light sources using phototransistors as detectors for both transmitted and scattered light.

transmitted.⁴⁹ For the LabWorks measurements, a phototransistor was used. The photodiode did not generate enough current to produce a stable signal, while the photodarlington produced current in excess of the LabWorks interface's 2048 μA maximum.

After selecting the infrared LED, the Hach standard solution was diluted four times, and nephelometry measurements were made on all solutions. The results of these measurements are summarized in Table 3.

| Concentration (NTU) | Scattered Light (μA) | Transmitted Light (μA) | Ratio: Scattered/Transmitted |
|---------------------|-----------------------------------|-------------------------------------|------------------------------|
| 0 | 0.0558 | 75.3985 | 0.000740 |
| 800 | 0.9945 | 65.8986 | 0.01509 |
| 1,600 | 1.7669 | 57.0431 | 0.030974 |
| 2,400 | 2.4360 | 46.5445 | 0.052337 |
| 3,200 | 2.4721 | 34.2313 | 0.072216 |
| 4,000 | 2.8172 | 20.2865 | 0.13887 |

Table 3. Results of turbidity readings of dilutions of the Hach standard.

For just the scattered light (simple nephelometry readings), the results are linear for concentrations through 2,400 NTU. After that point, the sensor goes blind and quantitative information is no longer reliable (see Figure 23a). With the 3,200 and 4,000 NTU data points eliminated (Figure 23b), the readings are quite linear and concentrations of unknown solutions can be determined from data in this region.

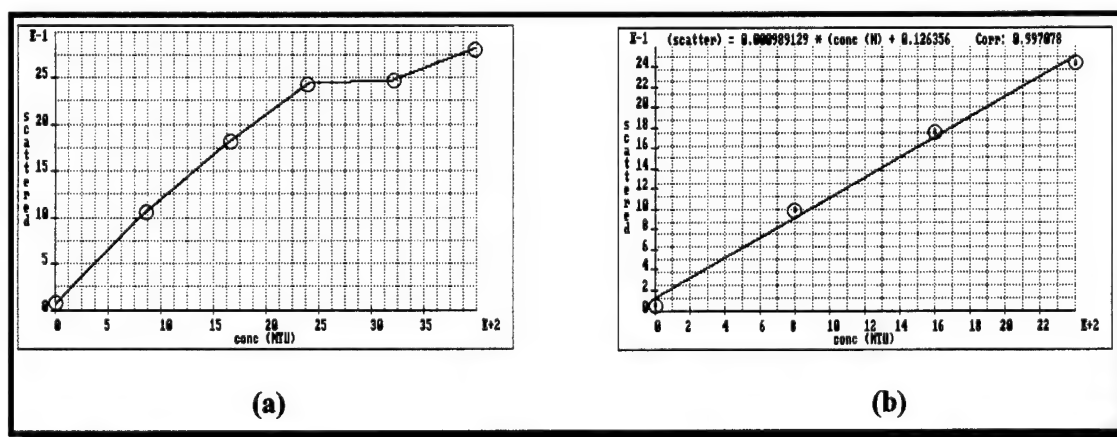


Figure 23. Simple nephelometry data with (a) and without (b) data at 3,200 and 4,000 NTU.

If the transmitted light is included with the scattered light, the dynamic range of the readings significantly improves. Figure 24a indicates that the nephelometric ratio data stays linear through 3,200 NTU. Higher concentration unknowns, therefore, are better determined using the ratio method. Figure 24b shows the calibration line obtained with the 4,000 NTU point removed.

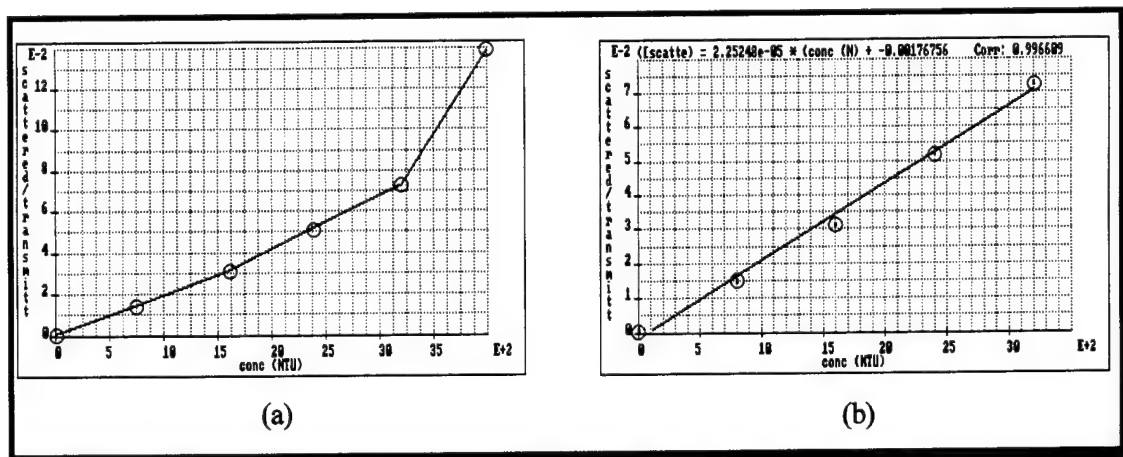


Figure 24. Ratio nephelometry data with (a) and without (b) 4,000 NTU data.

The experimental application of the LabWorks turbidimeter is discussed in Chapter 9 as part of the optical spectroscopy unit. The experiment involves calibrating the turbidimeter and measuring the concentration of an unknown sulfate solution. Treatment with barium chloride causes a barium sulfate precipitate that scatters light very well.

Conclusions

Light scattering is an effective method for measuring small amounts of detritus in aqueous solution and other solvents. This method is especially viable for industrial processes and in determining the purity of drinking water systems. Because of the importance and utility of industrial and scientific turbidity measurements, this concept should be presented in introductory college chemistry courses. In the past, the prohibitively high cost of commercial turbidimeters has prevented this concept from being widely taught in laboratories. Development of the LabWorks turbidimeter introduces a cost-effective device that can make this valuable education and training possible.

CHAPTER 4

SOFTWARE INNOVATIONS: COMMUNICATIONS

The first software applications described in this project exploit the computer's capability as a communication tool. Using the Internet and the World Wide Web (WWW), teachers can communicate with students, and students can find information on almost any subject. Communication software engages students in the first two learning levels of Bloom's taxonomy, knowledge and comprehension. As an administrative tool, communication software maximizes an instructor's flexibility, and frees up valuable class preparation time.

In the laboratory, user-friendly software can also streamline the experimental data acquisition process by making the measurement apparatus easy to use. Many software applications today are made user friendly by incorporating on-line help files. Help files allow a computer program to tell users how the program runs. The purpose of this type of communication is to maximize productivity and minimize time spent figuring out how the software works. Effective help files improve chemistry data acquisition software by keeping students focused on what they are measuring, rather than on the measuring devices themselves.

This chapter describes the WWW and on-line help applications, and how these tools allow students to learn at higher learning levels of Bloom's taxonomy.

Figure 25 shows the relationship between the tools developed in this chapter, the actions students perform in the laboratory, and the overall goals of this project.

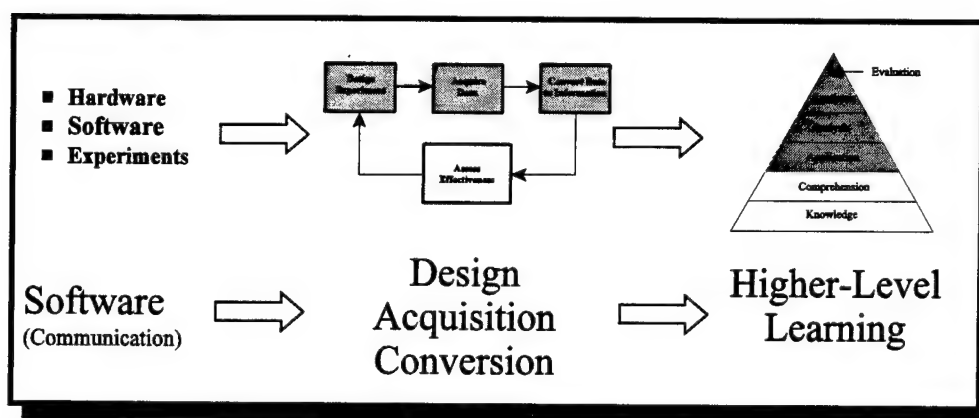


Figure 25. The relationship between the tools developed in Chapter 4 and the overall project goal. Communication software facilitates experiment design, data acquisition, and conversion of data to information, leading to higher levels of learning according to Bloom's taxonomy.

Statement of Original Work

While using the World Wide Web as an educational tool is certainly not an original idea, web pages devoted to chemistry courses at Montana State University are new to the curriculum. The web pages described in this chapter and the surveys eliciting student feedback on the pages are the original work of the author. The methods of creating, uploading, and maintaining the web pages were gleaned from various sources and combined into a single method as part of this project. The help files for LabWorks for Windows 95 are also the author's original contribution.

Chemistry and the World Wide Web

The advent of the Internet and its expansion over the past several years has greatly increased the ability for people to communicate. Electronic mail (e-mail) and the WWW allow messages, data files, and other information to be shared instantaneously. Computer users who have Internet access can capitalize on this information sharing capability. Internet access is available commercially for a modest fee, but nearly every college and university allows their students to use the Internet on campus at no charge beyond normal tuition and fees.

Because education involves the sharing of information, the Internet is an ideal teaching tool, and introductory chemistry courses can benefit from this technology as much as any other course.⁵⁰ This chapter demonstrates how the Internet and the WWW can be used to enhance undergraduate chemistry courses.

The WWW as an Administrative Tool

Effective classroom administration is a significant part of a successful chemistry class. Students need to know which textbooks to purchase, where and when classes meet, and, most importantly, where and when exams will be held. These pieces of information could be classified as knowledge, according to Bloom's taxonomy, even if they are not chemistry specific. This type of learning is taken for granted many times, but for new students, administrative procedures are a source of frustration. Any help that teachers can provide to ease administrative burdens will expedite students' mastery of chemistry

concepts. The WWW can help students start their journey to higher levels of Bloom's taxonomy.

While there is no substitute for advanced planning, unexpected events can hinder the smooth execution of any chemistry course. When changes occur, such as a rescheduled exam or a syllabus change, an instructor must spend time and money producing new handouts to give students. Paper and photocopier costs are steadily increasing, and shrinking budgets seldom allow for excessive photocopying. The WWW is an effective cost-saving alternative to printing schedule changes.

The WWW can be electronic bulletin board that students can check regularly for administrative changes. Teachers may encounter resistance to using this new information medium, but once students realize the necessity of checking the WWW, they will comply.

The WWW as a Reference Tool

"Never in the history of education has so much information been so easily accessible to so many." This allusion to Winston Churchill's description of the Battle of Britain⁵¹ accurately describes the power of the WWW as a reference tool. Chemistry education periodicals, such as the *Journal of Chemical Education*, post many articles and abstracts on their web pages.⁵² *The Chemical Educator* is a journal published solely on the Internet; the only way to subscribe to this journal is on-line.⁵³

Internet search utilities such as Alta Vista⁵⁴ and Yahoo⁵⁵ bring up lists of web pages when users type in just a few keywords. The number of chemistry-related information archives is growing constantly, and educators are encouraging their students

to use these resources.^{56,57} With these types of research tools so widely available, students should no longer be intimidated when asked to find “at least two references besides your textbook.”

MSU Chemistry on the World Wide Web

In the 1997 spring semester, a WWW page was developed for Chemistry 121, an introductory chemistry course at Montana State University (see Figure 26). This page includes the course syllabus, homework assignments, test dates and locations, as well as answers to homework problems. The page also has links to other course-related web pages.

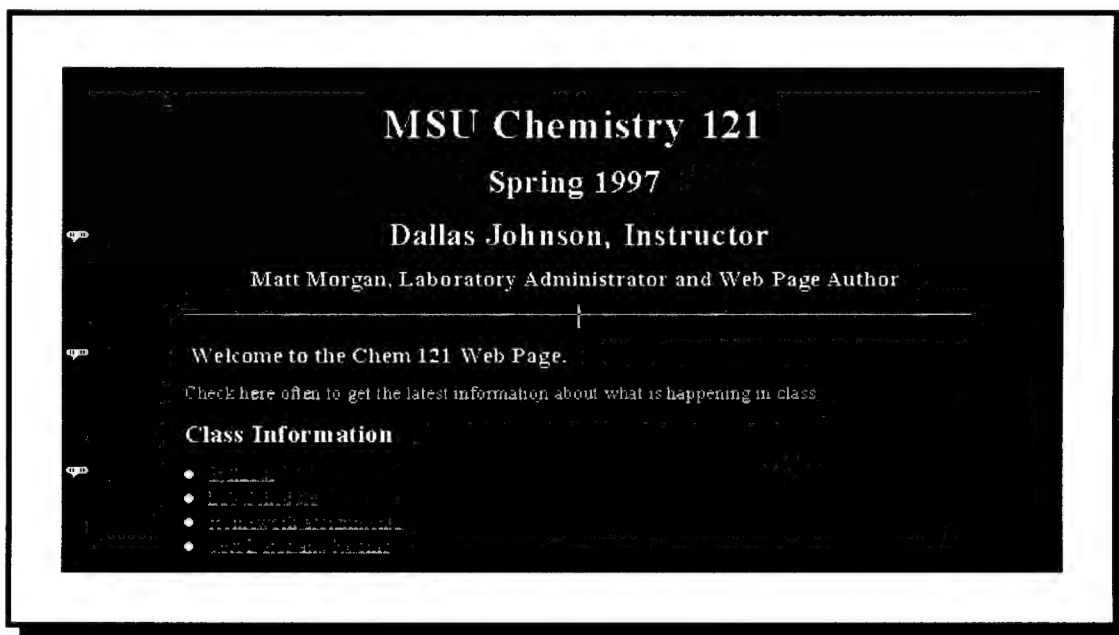


Figure 26. MSU Chemistry 121 web page.

Selected laboratory teaching assistants (TAs) also created web pages for their own lab sections. Each individual web page relayed information that was relevant only to the TA's particular section. Students received the Internet address of the different web pages, and were encouraged to check the pages often for the latest information.

To track the frequency of web page usage, each Chemistry 121-related web page had a counter that tallied the number of "hits," or times students accessed the web pages (Figure 27). Hit totals for the various Chemistry 121 web pages are summarized in Table 4. In addition, a survey was distributed near the end of the semester to determine students' opinions on the usefulness of the web pages. Surprisingly, survey results indicated that while the Chemistry 121 home page had 294 hits throughout the semester, only 10 percent of the 127 students enrolled in the course regularly accessed the page. Course web pages as information sources are considered worthwhile, as they have continued to be a part of MSU's chemistry 121 course.

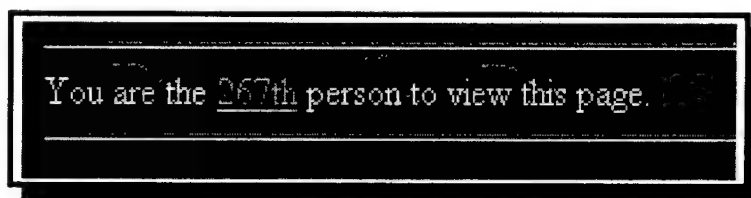


Figure 27. Web page usage counter.

| Web Page Title | Number of Hits |
|---------------------------|----------------|
| Chemistry 121 Home Page | 294 |
| Homework Solutions Page | 162 |
| Why Wear Goggles in Lab | 71 |
| Matt Morgan's Lab Section | 116 |
| T. N. Jones' Lab Section | 25 |
| Equation Balancing Guide | 36 |

Table 4. Chemistry 121 web page usage for spring 1997 semester.

Problems With Access. The Internet's greatest strength is its universal accessibility. Unfortunately, this can also create problems. If a particular web page becomes popular, the server storing the page can become overloaded with computer users trying to access the page. In this case, the server's communication hardware cannot meet the demand, and response time slows down. When this occurs, users must wait while the page loads slowly. This bandwidth problem plagues an increasing number of Internet users, and the problem may get worse before it gets better.^{58,59}

One solution to the bandwidth problem is to use a limited type of network called an Intranet. Only local users have access to Intranet web pages, and communication lines are far less likely to be overloaded by a large number of users. For college or university course web pages, Intranets are an obvious solution to the bandwidth problem because the

only users interested in accessing a specific course's web page would be students who are enrolled in the course and have access to the internal network.

Another disadvantage of web pages is that they are a one-way communication medium. Students can receive information, but they cannot communicate back to the web page author beyond sending an e-mail message to addresses listed on the page. Internet news groups provide another information-sharing option. There are no graphics or formatted text in news groups, but these forums allow students to share information and course tips. In a news group, students post messages to which all members can reply.

What is a Web Page?

A WWW page is a computer-generated text document that is stored on a type of computer called a web server. Web pages can be viewed using a special type of software called a web browser. Netscape Navigator and Microsoft's Internet Explorer are two popular web browsers. Each web page has a unique address, and users type this address into their web browsers to make the page appear on their computer screens.

Web page addresses are long and often difficult to remember. For example, the MSU Chemistry 121 web page is located at `MONTANA.EDU/WWWCHEM/CHEM121.INDEX.HTML`. To make accessing an often-used web page easier, students can place the address on a "bookmark" that automatically accesses that page address with a single mouse click.

Web pages are unique in that they are platform, or processor-independent. A web page written with a Macintosh computer can be viewed by a computer running another operating system, such as Windows 95 or OS/2. The text, graphics, and sounds

embedded in these pages can be viewed by any computer running a compatible web browser.

Web pages include many types of formatted text. Formatting options include page background, text color, and headings, as well as active links (see sidebar). Each of these text formats requires that a specific command be placed in the web page source document. The language used to create web pages is called hyper-text markup language, or HTML.

HTML documents are basic text documents with formatting codes added. These codes are called tags, and are enclosed in left- and right-angled brackets (< >).⁶⁰ The commands enclosed in the brackets are placed both before and after the affected text, and can use either upper- or lower-case letters. For example, the command <href> is identical to <HREF>.

Creating a Web Page

The first tag found in an HTML file is <html>, which identifies the file as using the HTML format. At the end of the document, the command </html> closes the document. HTML tags control text size, placement, and attributes such as bold or italic. While the original set of HTML tags is limited, new commands are constantly being developed.⁶¹ Figure 28 shows the source document for the web page in Figure 25. This is only a portion of the entire page, yet it shows a variety of different tags.

Links in web pages—

The underlined text in a web page represents a *link* to sections of the same page or links to other web pages. Rather than scrolling through a lengthy document or typing the address of another page, clicking the pointer on this text moves the user to the requested section. All of the Chemistry 121 web pages are linked together. By locating one of the pages, students have access to all related pages.

```

<html>
<head>
<title>MSU Chemistry 121 HomePage</title>
</head>
<body background="greenmar.gif" text="#fefdfc" link="#00ff00" vlink="#ff66b3"
alink="#ff0000" bgcolor="#c0c0c0">
<h1 align="center">MSU Chemistry 121 </h1>
<h2 align="center">Spring 1997 </h2>

<h2 align="center">Dallas Johnson, Instructor</h2>
<h4 align="center">Matt Morgan, Laboratory Administrator and Web Page Author </h4>

<p align="center"><hr>

<h4><strong> Welcome to the Chem 121 Web Page. </strong> </h4>
Check here often to get the latest information about what is happening in class.
<h3>Class Information</h3>

<ul>
<li><a href="#Syllabus">Syllabus</a> </li>
<li><a href="#Lab Schedule">Lab Schedule </a> </li>
<li><a href="#Homework">Homework assignments </a></li>
<li><a href="#Test Info">Test Dates and Rooms </a></li>

```

Figure 28. Sample HTML source code for the web page in Figure 25. The formatting codes require as much typing as the text that is displayed.

The tag <title> displays text in the largest size possible. Other text sizes are obtained by specifying heading sizes <h1> through <h6>. The <body background=> tag specifies a picture file to be used as the page background and sets the colors of normal and linking text. A web page author can use many different tags to make pages informative and pleasing to the eye.

Figure 28 shows that there is often as much formatting text as there is visible text. Web page construction and maintenance is made easier by using a software package designed to create web documents. As with most new technologies, there are advantages and disadvantages to using web page creation software.

The Chemistry 121 web pages were created using Internet Publisher, which is part of the Corel Word Perfect 7.0 suite of applications.⁶² This software displays web pages as they are seen through a web browser, and allows changes to be made from this view. Figure 29 shows the web page shown in Figure 26 with the font select window open. Notice there are far fewer formatting commands available for web pages than there are for normal word processing.

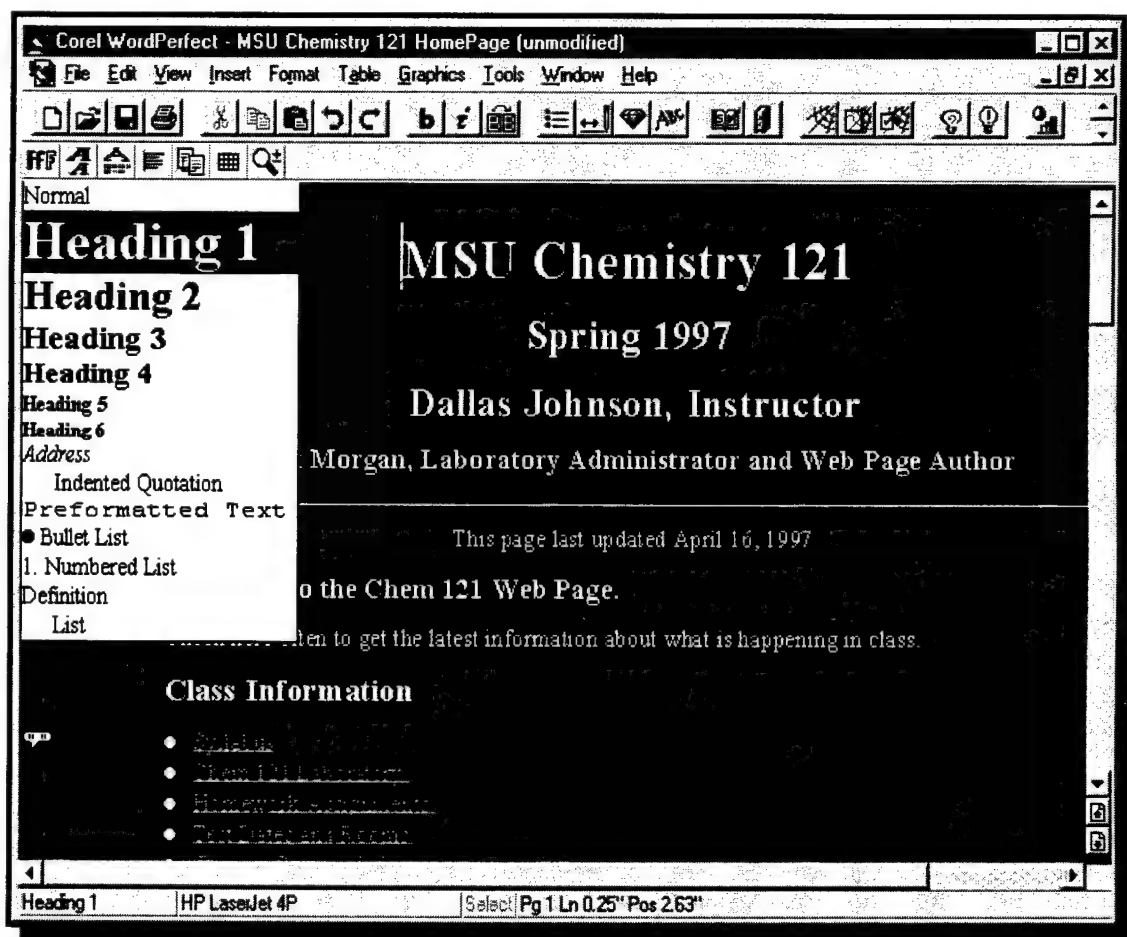


Figure 29. Word Perfect's Internet Publisher. With this tool you may edit web pages and immediately see the results of your changes.

Internet Publisher is a useful tool which can, in many ways, simplify web page creation. Its principle advantage is its visually accurate editing mode, called WYSIWYG, or “what you see is what you get.” However, there are some disadvantages to using Internet Publisher. The editor is very versatile, but it does not allow complete formatting of web page files. During creation and maintenance of the web pages for Chemistry 121, it was often necessary to open the web page files as text documents and manually edit HTML tags. Establishing links using Internet Publisher was especially difficult. Also, the automatic hit counters on each page had to be placed manually. Finally, the editor’s visually “accurate” views were not always reliable—what was seen in the editor screen was not always what was displayed in a web browser.

Applications like Internet Publisher generally are efficient tools when creating web pages, but web page authors should be prepared to make manual changes if necessary. Future versions of web page creation software will hopefully recognize and correct these drawbacks.

Even with web page development tools, creating and updating web pages is a time-consuming process. Most web page editing sessions involve simultaneous use of three computer applications: a web page editor, web page browser, and file transfer utility. The three open applications in Figure 30 are Corel Word Perfect, Netscape Navigator,⁶³ and WS FTP-95.⁶⁴ The web page is modified using the editor, copied to the server using the transfer utility, and then viewed using the web browser. This iterative, three-step process is recommended over simply editing and copying the files to the server due to the potential problems mentioned previously.

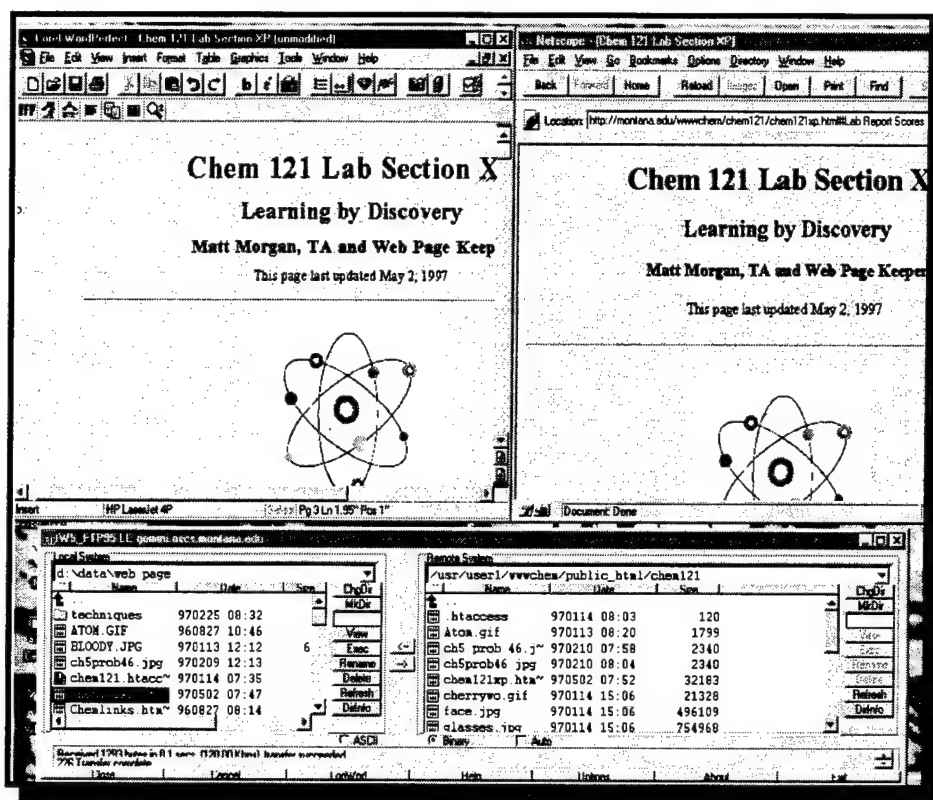


Figure 30. The three applications open in a recommended web page editing session. All three of these tools are necessary to ensure that the changes made will be properly displayed on the web page.

WWW Conclusions

The World Wide Web can be used effectively to enhance teacher-student communications. Creating and maintaining web pages is a time-consuming process, however, and the pros and cons of employing this form of technology should be considered before choosing to implement a web page. Even if schools choose not to generate their own web pages, the WWW is an outstanding and time-saving reference tool allowing students to easily access a wide range of information.

On-Line Help Files

The second form of software communication discussed in this chapter involves on-line application help. On-line help allows students to learn at higher levels by making laboratory tools easier to use. Students can then focus on the process of science and higher-level learning, rather on the tools they are using. This section outlines a short history of software documentation, followed by the evolution of help files, and finally the creation of help files for a specific application, LabWorks for Windows 95.

Instructions for using software have traditionally come from printed manuals. Printed documentation can be inconvenient because it requires users to work simultaneously with two different types of media—a printed page and a computer screen. One study has shown that learning using two different media types is not as effective as working with a single type.⁶⁵ When a student has to read a reference manual, put the manual down, then look at a computer screen, he or she has to change focus, resulting in a loss of concentration and productivity. If help can be obtained from the computer program itself, then students can learn to use the program quickly and easily.

In the late 1980s, Macintosh and Windows 3.1 programs started to include information files to provide basic instructions on how to operate the computer applications. These help files were accessed by selecting commands from a “Help Menu.” Although they were well-intentioned, these early help files were neither helpful nor useable. The help files were written by computer programmers rather than professional writers, and little effort was spent to determine the kinds of information

users needed to effectively run the applications. As a result, these on-line resources remained largely unused.

With the advent of Windows 95 and its associated applications, on-line help screens became much more effective. During beta testing of the Windows 95 operating system, Microsoft extensively tested the effectiveness of its on-line help.⁶⁶ Because of this testing, the content and usefulness of the help files greatly improved. Users could now receive information pertaining to frequently used topics. The multitasking ability of Windows 95 also allows the on-line documentation and the application itself to run simultaneously on the computer.

A primary factor leading to the increased effectiveness of on-line help files was the decision of software manufacturers to have nonprogrammers write help file content. Computer programmers are trained to design software applications, but in many cases, they do not possess the written communication skills necessary to write user-friendly help files. In writing the LabWorks help files, a chemist with extensive teaching and LabWorks experience and strong writing skills was teamed with programmers to create on-line help that was relevant and applicable to LabWorks for Windows 95.

Writing the Help Files

The LabWorks for Windows 95 help files were written using two software packages, Microsoft Word for Windows⁶⁷ and Microsoft Help Workshop.⁶⁸ The help screen contents were written using Word, and the separate help files were compiled into a

single help file using Help Workshop. This single help file has the file extension .HLP, and it can be read using Windows 95's built-in help.

After the help files were written, they were saved as a type of file called rich text format (RTF). RTF files allow files with special text formatting, such as footnotes and hidden text, to be transferred to different computer programs or operating systems.⁶⁹ Different help topic screens were separated by page breaks, putting one help topic on each document page. Theoretically, one help file could be written using a single RTF file. However, because a single help file might have hundreds of topic screens, that RTF file would be hundreds of pages long, and very unwieldy to edit. For that reason, the help topics for LabWorks for Windows 95 were divided into multiple files, each file covering a specific aspect of the program. Figure 31 shows the RTF topic files used in producing the LabWorks for Windows 95 help.

| | |
|----------------------------|-----------------------------|
| Build Edit Help.RTF | Input Sources.RTF |
| Builder Commands.RTF | Interface Front.RTF |
| Calibrate Sensors Help.RTF | LabWorks Tips and Hints.RTF |
| Error Messages.RTF | Navigating LabWorks.RTF |
| Experiment Notes.RTF | Perform Experiment Help.RTF |
| EZ Experiment Help.RTF | Spreadsheet Help.RTF |
| Help Overview.RTF | Troubleshooting.RTF |

Figure 31. RTF files used to make the LabWorks for Windows 95 help. Using many smaller files rather than a single, huge source files makes the source information much easier to manage.

On-line help allows users to move or “jump” from one related topic to the other or “pop up” information on demand. These jumps and pop-ups are programmed into the

topic files using footnotes and special text formatting. An annotated RTF file is shown in Figure 32.

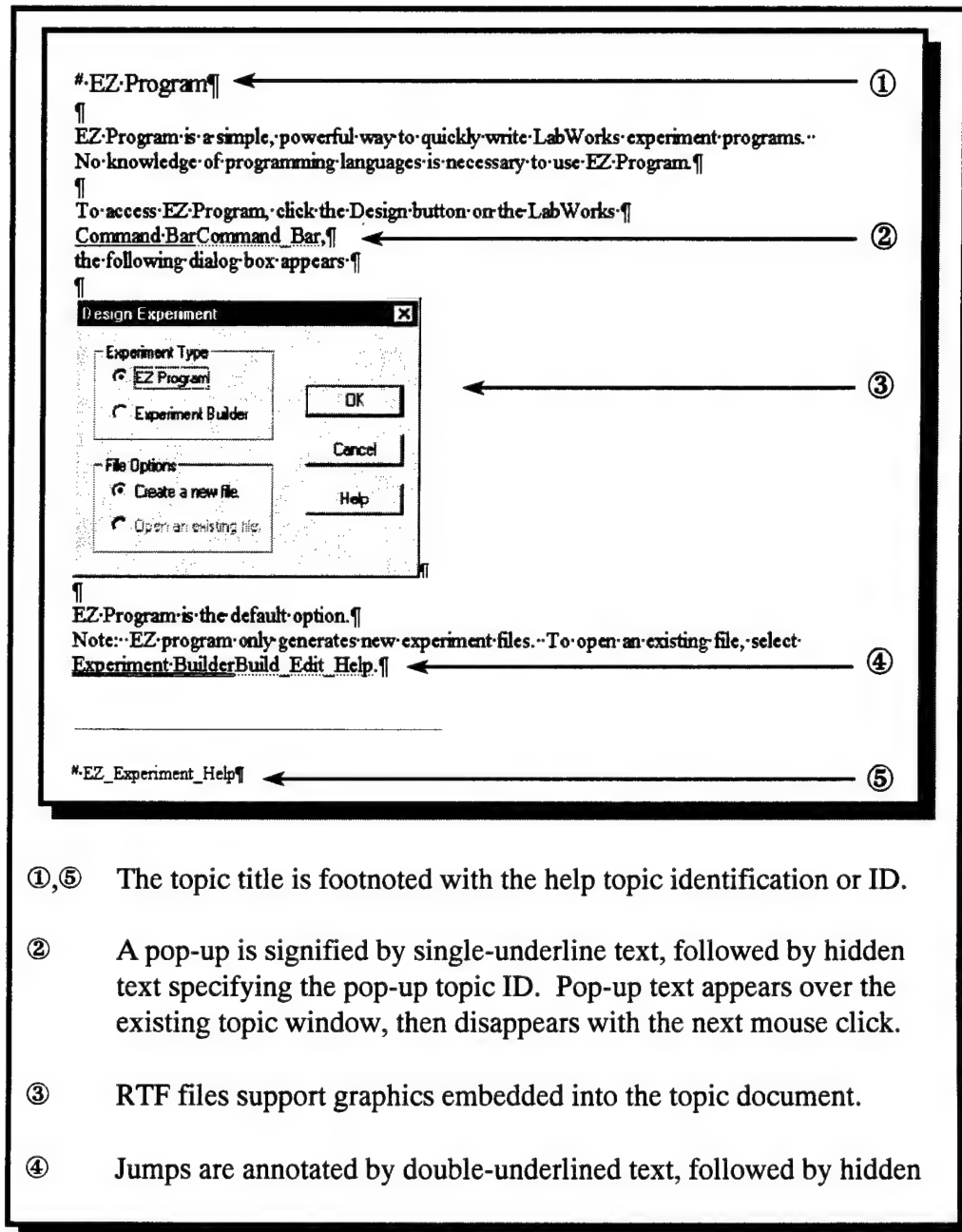


Figure 32. A sample RTF file, with comments on the different parts.

After the component RTF files are compiled into a single help file, the formatting commands are no longer visible. These formatting commands facilitate text links, jumps, and pop-ups. The help window generated by the RTF file in Figure 32 is shown in Figure 33. Figure 33 also shows an activated pop-up. This special box appears over the existing help document, and then disappears with the next mouse click.

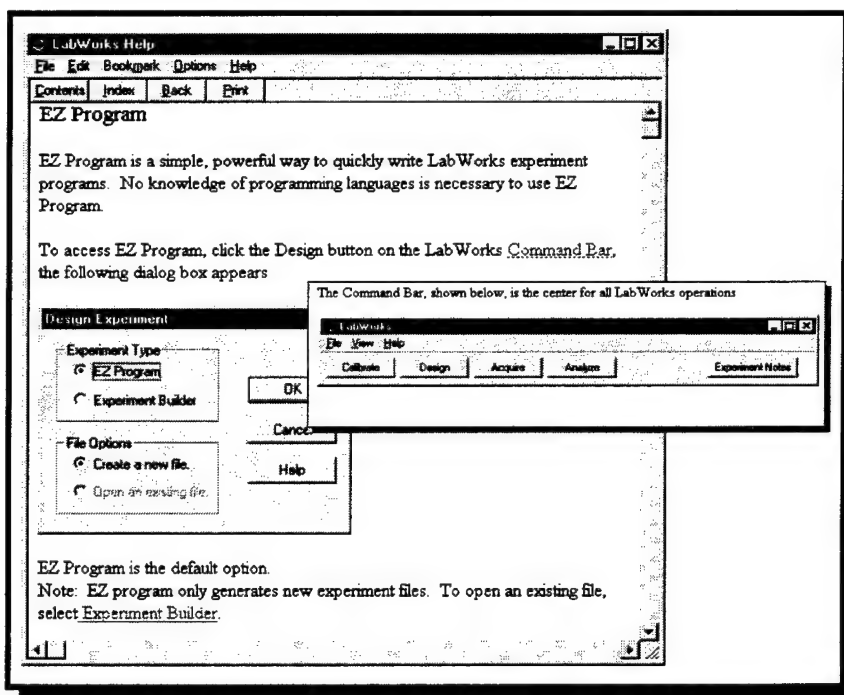


Figure 33. Help screen generated by RTF file in Figure 32, with the Command Bar pop-up displayed.

Context-Sensitive Help

Another advantage of help files in Windows 95 is the availability of context-sensitive help. Context-sensitive help allows users to get relevant information directly from the software application, without having to look at superfluous help screens.⁷⁰ For example, when running LabWorks for Windows 95 and calibrating a pH1 sensor, the software displays the dialog box shown in Figure 34.

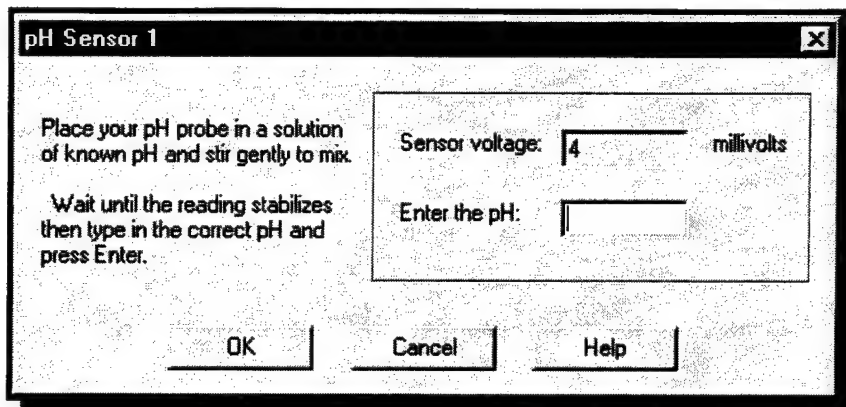


Figure 34. pH calibration screen from LabWorks for Windows 95. Clicking on the Help button at the lower right side of the screen brings up the pH 1 help topic. There is no need to navigate through the entire help file to find this topic.

To bring up the help screen for calibrating pH1, users click on the Help button in the dialog box or press F1 on the keyboard. This brings up the pH1 help screen without having to navigate through the entire LabWorks help file.

The LabWorks for Windows 95 help file also contains an index that allows users to type in a word or phrase and immediately jump to that help topic. This index, shown in Figure 35, is activated by placing a special footnote in the RTF file for the particular help screen. The footnote is a capital K, which stands for “keyword.” A dollar

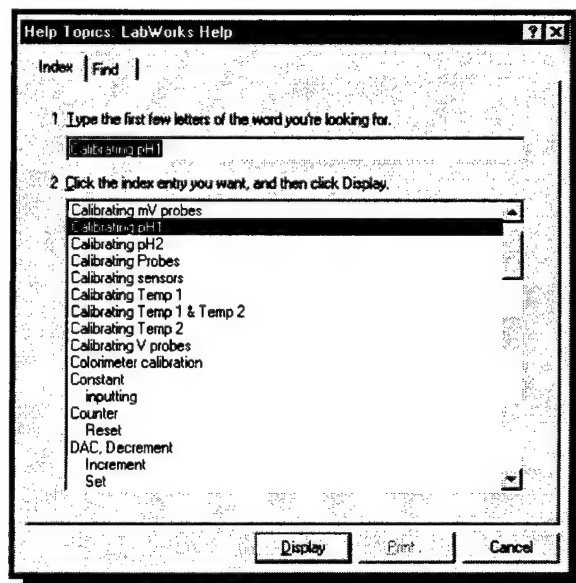


Figure 35. Help file index. Typing the name of a desired topic highlights the names of related help screens.

sign (\$) is also inserted, which displays the title of the help screen. A sample RTF file with displayed footnotes is shown in Figure 36.

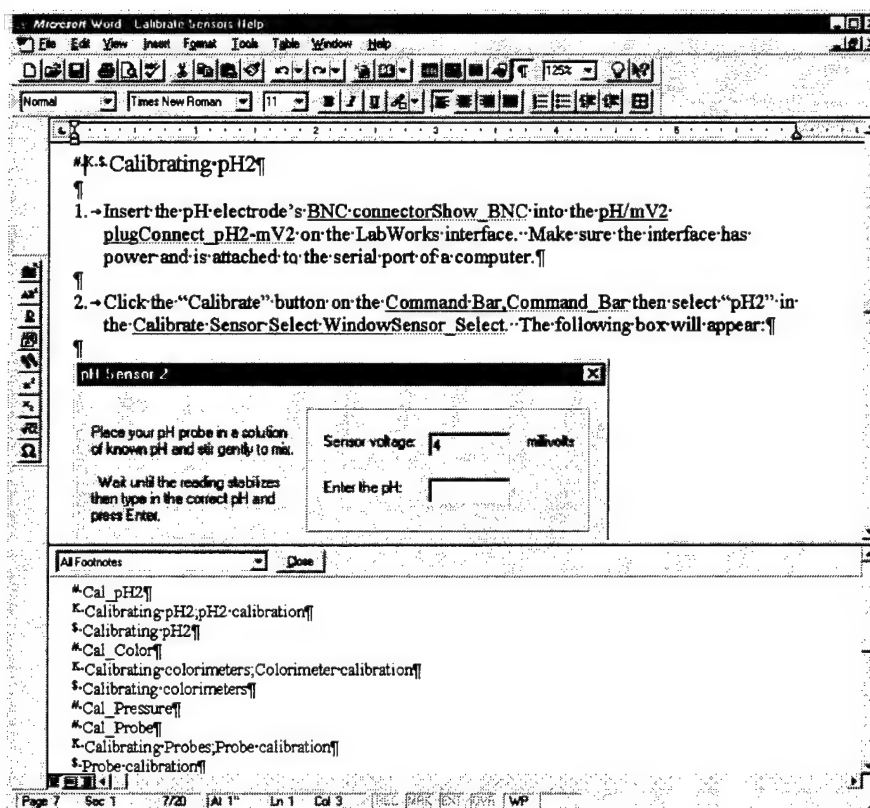


Figure 36. Sample RTF file showing keyword footnotes. Like jump and pop-up footnotes, keyword footnotes do not appear in the compiled help file.

HTML vs. RTF

Like help files, HTML source files incorporate special text formatting and links, and can be viewed across multiple platforms. Additionally, HTML files can include small, built-in applications written in a computer language called Java. These “applets” may also be run by different computers and operating systems. For these reasons, HTML is a valid alternative to the existing RTF-based help system. Future applications may include help based on HTML, incorporating interactive Java applet tutorials. At the time

of this writing, Microsoft's latest application development suite, Visual C++ 5.0, has help files that were written using the HTML format.⁷¹

Help Conclusions

Creating help files, like creating web pages, is a time-intensive process. Instructors must decide if the insight students gain from referencing these files is worth the time taken away from other projects. Help files are normally associated with computer applications, but help files can provide instruction for any topic. When tools and techniques are easy to use, students will be more successful and confident when working in the laboratory. This increased comfort is an important first step toward higher-level learning in the laboratory.

CHAPTER 5

SOFTWARE INNOVATIONS: DATA ACQUISITION

The next type of software developed by this project controls data acquisition tools. One of the biggest obstacles to effectively employing technology in chemistry laboratories is making the equipment easy to use and understand. All scientific measuring devices require a certain amount of training, or learning curve, but the best tools are those that can be up and running as quickly as possible. The help files discussed in Chapter 4 were one improvement aimed at making measuring tools easier to use. This chapter focuses on the measurement software itself.

The software tools described in this chapter range from broad applications to specific experiments. The following software tools are examined:

- LabWorks for Windows 95
- EZ Program – a subset of LabWorks
- Hewlett Packard HP 48 calculator control of the LabWorks interface

All of these tools make acquiring data easier for students and laboratories less expensive to set up and maintain for instructors. The specific focus in this chapter is on data acquisition, with the overall goal of higher-level learning being maintained. Figure 37 illustrates the contributions of this chapter toward higher-level learning.

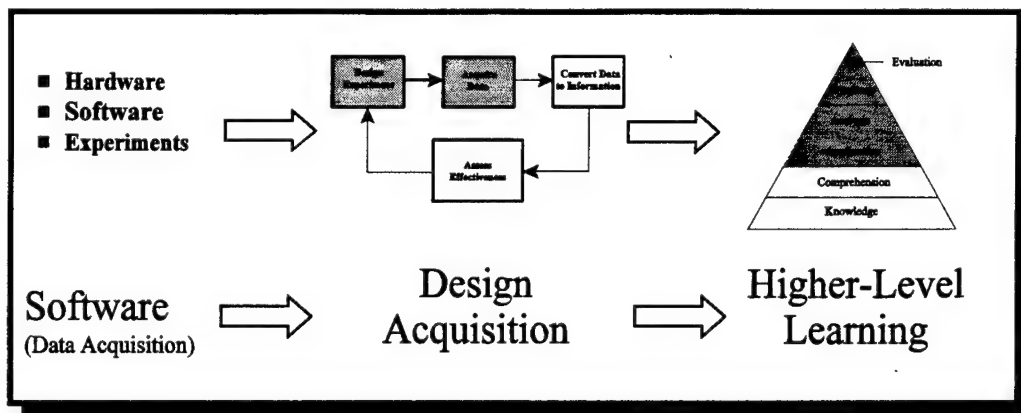


Figure 37. The link between data acquisition software and the project goal of higher-level learning. The actions made easier by better software enable students to learn at higher levels of Bloom's taxonomy.

Statement of Original Work

LabWorks for Windows 95 and EZ Program were written with significant design input from the author, although no computer code was designed as part of this project. The HP 48 calculator control of the LabWorks interface is almost entirely original work. The initial idea was suggested by Dr. John Amend, and LabWorks interface command codes were generously supplied by SCI Technologies. The adaptation of the LabWorks computer code to the HP 48 and all HP 48 programs were written as part of this project.

LabWorks for Windows 95

"User-friendly" is a term that is continually applied and misapplied to new technology. A truly user-friendly device in a chemistry laboratory, for example, allows students to focus on the measurements they are making and not on the technology itself

(Figure 38). The improvements made to the LabWorks software are dedicated to making the LabWorks measurement system easier to use.

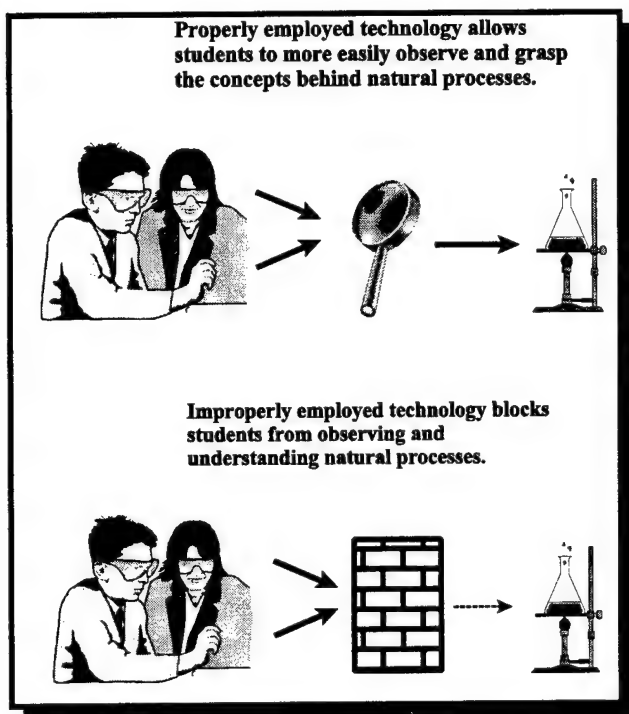


Figure 38. How the appropriate use of technology affects students.

With any computer-based measuring system, the software is the link between the user and the hardware (Figure 39). Many companies add extra functions to new software versions, often making the software more complicated and difficult to use. This trend toward “featuritis” results in lost productivity, as teachers and students struggle to keep up with constantly changing technology.⁷² The goal of updating software in this project is to make computers easier to operate and understand. With the new LabWorks software, computer technology is transformed into a learning aid which magnifies the

process of science—students do not have to worry about getting the computer and interface to work, and can instead concentrate on making measurements.

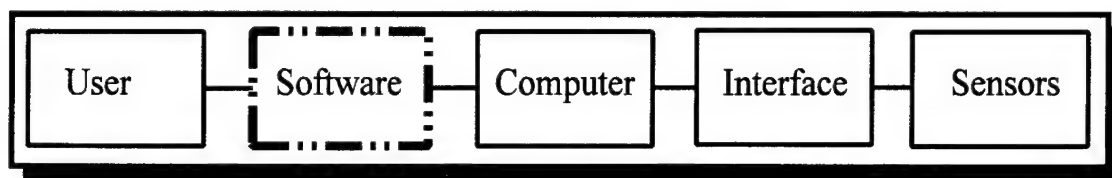


Figure 39. Software is key to making technology user-friendly.

The MSU and LabWorks interfaces have been using MS-DOS software at Montana State University student laboratories since 1989.⁷³ As more students became accustomed to using Windows 95, SCI Technologies, the manufacturers of LabWorks, began designing a Windows 95 version of their software. With the goal of increased user-friendliness in mind, SCI enlisted the help of the Amend research group at MSU to provide teacher and student input for the new software design.

The result of this collaboration was a four-step approach allowing students to design their own data acquisition programs using the LabWorks interface system. The four steps are Sensor Calibration, Experiment Design, Data Acquisition, and Data Analysis. Students access these functions by clicking on one of four buttons located below the program's main menu bar, which is shown in Figure 40. The order of the buttons follows the process of the experimental portion of the scientific method.

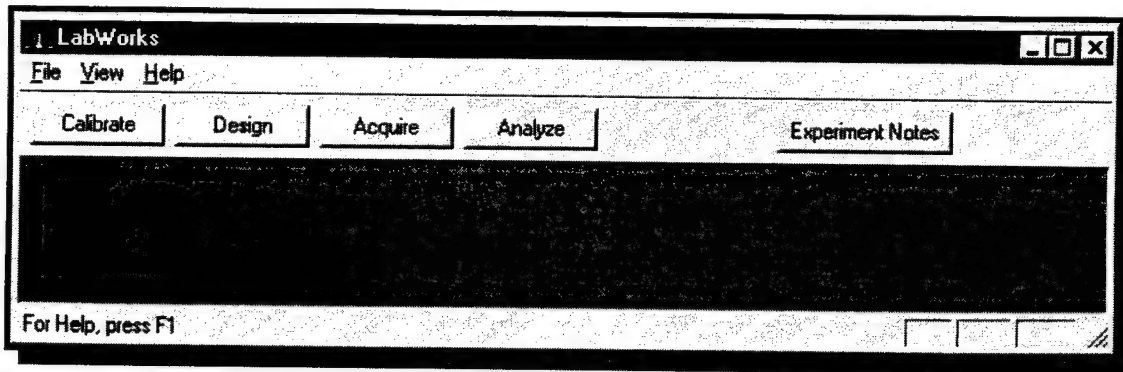


Figure 40. The four main functions of the LabWorks for Windows software. The buttons are arranged according to the actions performed during the process of science.

EZ Program

The Sensor Calibration, Data Acquisition, and Data Analysis procedures are very similar between the DOS and Windows 95 versions of LabWorks.⁷⁴ The Experiment Design function in the new software, however, has been greatly simplified. In addition to the traditional experiment builder transported from the DOS version of LabWorks, the Windows 95 version includes an experiment builder called EZ Program.

The experiment builder introduced in the DOS version of LabWorks allowed students to design and build their own data acquisition programs. Its primary advantage was a menu-driven interface that eliminated command syntax errors. Beginning users, however, were presented with a daunting array of menu choices for data input sources and destinations. Students often had to navigate through multiple screens to insert a command in their data acquisition programs. Figure 41 shows the Build Edit screen from the DOS version of LabWorks.

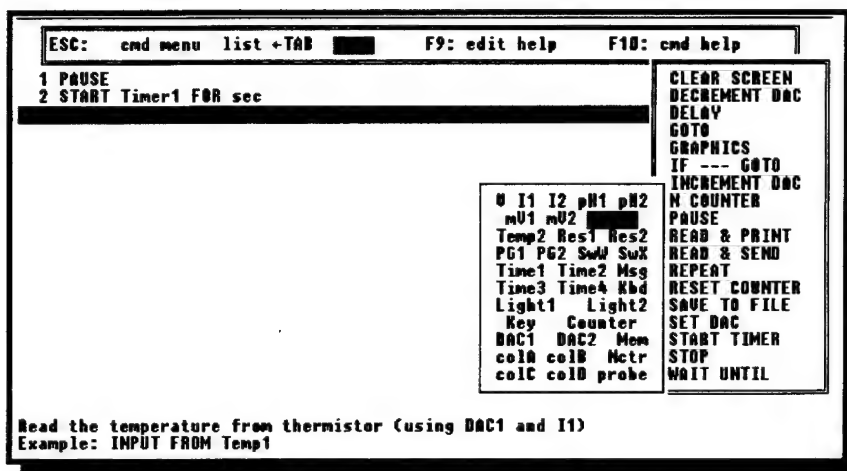


Figure 41. LabWorks for DOS experiment builder. The large number of sensor choices is daunting to students who are unfamiliar with using technology.

EZ Program in LabWorks for Windows 95 simplifies the experiment-building process, reducing the number of design parameters and putting them all on a single screen. Figure 42 shows a screen shot of EZ Program. Students select one or two sensors for data acquisition and a delay value between measurements. The experiment time, measured in seconds, is the default independent variable, but keyboard input or a digital counter can also be selected. After the sensor choices are made, students click on the Acquire button to begin recording experiment data. Much of the flexibility and power of the original DOS builder is retained in this application, but the learning curve for novice users is significantly reduced.

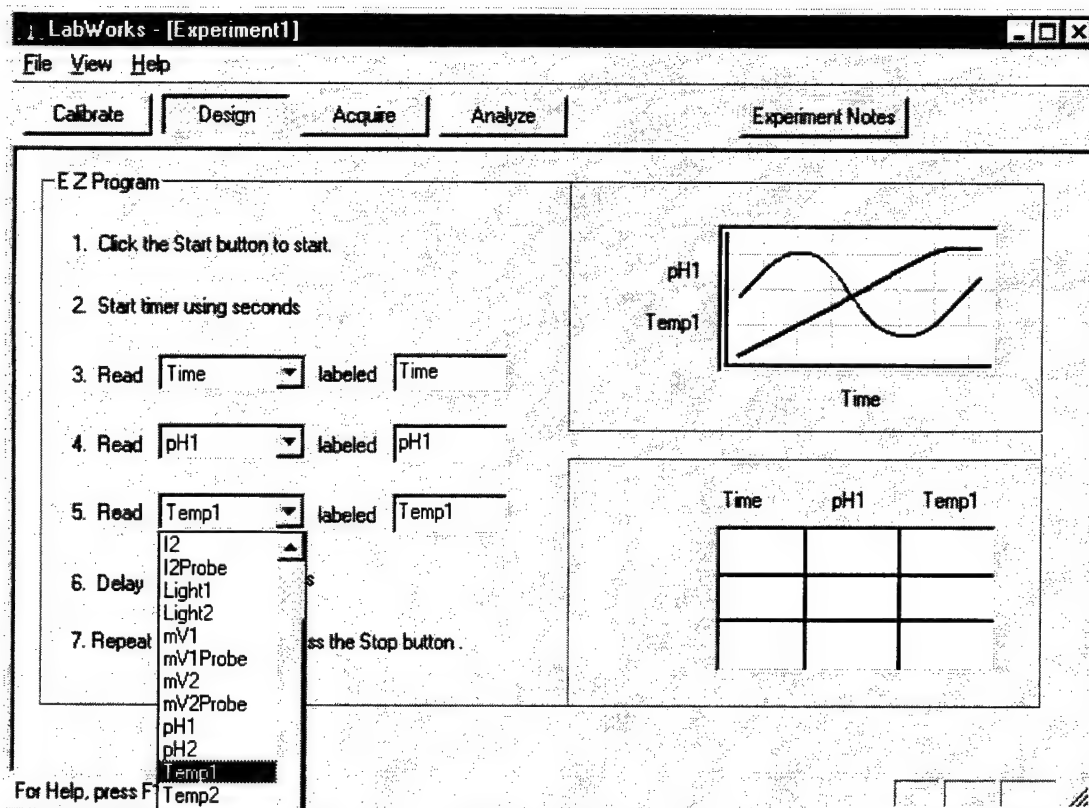


Figure 42. EZ Program experiment builder. This tool is much easier to use than the LabWorks for DOS experiment builder.

Using EZ program, students make choices about which sensors to employ to measure specific physical properties. This choice aspect allows students to move beyond the comprehension and application learning of traditional “cook book” experiments to the analysis and synthesis levels. While the learning levels move up the Bloom scale, the mechanics of making the choices are very simple, and the learning curve required to use the technology is diminished.

Controlling the LabWorks Interface with the HP 48 Calculator

As stated in Chapter 1, technology is available to facilitate higher learning in introductory chemistry laboratories, but obstacles prevent the technology's proper employment. Laboratory instructors may continue to use "proven" teaching methods because technological tools necessary for higher learning are either too expensive, difficult to understand, or both. The LabWorks interface is an affordable and powerful system, but it requires a personal computer (PC) to control its data acquisition interface. Schools with limited space or budget constraints may not be able to support a large number of computers in their classrooms. An alternative to using a PC to control the LabWorks interface is the Hewlett Packard HP 48 series of hand-held calculators.

HP 48 calculators have the ability to communicate with the LabWorks II interface via serial link. Like PCs, the calculators can send commands and receive LabWorks-acquired data. The data can also be stored and displayed in both graphical and textual formats. At \$100 per unit, HP 48 calculators are also less expensive than PCs, in addition to occupying much less desk space. This section discusses the benefits of using this alternative to personal computers, how the calculator can communicate with the interface, and specific advantages and disadvantages of calculators versus PCs for interface control.

Considerations for Calculator Control

Purchasing and implementing technology requires that time and money be spent up front to reap the educational benefits later. Any advances made to decrease these

initial costs will make the technology and the higher learning available to more students.

Once schools decide to implement the LabWorks system, the laboratory administrator must:

1. purchase the interfaces/sensor packages;
2. acquire personal computers; and
3. find laboratory space for the equipment.

When looking for computers to control the LabWorks system, laboratory administrators do not necessarily have to budget for expensive, top-line models. Many college departments and local businesses periodically upgrade their computer systems, making older-generation PCs available at extremely low cost. The DOS version of the LabWorks software runs very well on older PCs⁷⁵ and it is relatively easy for a budget-limited laboratory administrator to obtain these computers second-hand.

Finding laboratory space for the equipment is the final, and perhaps most difficult, step. All but the most recent chemistry laboratories were designed without allowing space for computer central processing units, monitors, and keyboards. If not carefully planned, the arrangement of the required equipment will leave insufficient bench space for chemistry experiments. Montana State University and the U.S. Air Force Academy have developed innovative, space-conserving solutions.⁷⁶

A hand-held calculator with serial communication capability and a graphics display provides a low-cost solution to requirements 2 and 3. Calculators with these capabilities cost about \$100, and only occupy a few square inches of desk space. The control software can also be copied to student-owned calculators, reducing or eliminating the need for schools to purchase and maintain calculators for each student or lab station.

Two calculator models considered for LabWorks control were the Hewlett Packard HP 48 and the Texas Instruments TI-82. The HP calculator uses standard serial communication routines and a 4-pin-to-9-pin cable connector. The TI calculator is already part of an interface package called the Calculator-based Laboratory (CBL). The communication protocol used by the TI calculator is proprietary, which means that special decoding software must be loaded into the interface to enable communication. For this reason, the HP 48 was chosen for LabWorks control development.

Calculator/Interface Communications

Hewlett Packard Corporation manufactures a cable that enables their HP 48 calculators to connect to PCs via a 9-pin serial port. The LabWorks II interface also communicates with PCs using a 9-pin serial port, and a null modem adaptor is necessary to allow the calculator and interface to communicate with each other.

Chapter 3 asserted that the internal processor and memory in the LabWorks II interface made the software development in this project possible. The internal control commands that LabWorks II handles by itself allow the HP 48 to use a streamlined instruction set. To test this theory, communications were attempted between an HP 48 and an older LabWorks interface, using a serial-to-parallel converter. The older interface did not acknowledge commands from the calculator, demonstrating that the calculator depends on the LabWorks II interface's on-board intelligence for its communication.

Making Simple Measurements

Once communications were established between the calculator and interface, the next step was to send a command to the interface to make simple measurements. Simple measurements, in this context, are defined as those not using the LabWorks interface's analog-to-digital converter (ADC). The interface's on-board timer and digital counter are examples of functions employing simple measurements.

SCI assisted with this part of the project by supplying the machine-level command codes for the LabWorks interface. Using this information, the calculator was programmed to send a series of commands to the interface, then receive incoming data.

All data that is communicated between the calculator and the interface is in the form of ASCII characters. ASCII stands for American Standard Code for Information Interchange. Upper-case and lower case letters, numerals, and symbols all have assigned binary values. This binary-to-character encoding scheme has been accepted as a standard format for digital communication.⁷⁷

The HP 48 uses two commands, XMIT and SRECV, to transmit and receive data via serial link. Both commands and data are sent in 8-bit packets, or bytes, using ASCII characters. When numerical values are transmitted back from the interface, those characters are converted to numbers using the calculator's NUM command. Numbers sent to the interface (to set DAC values, for example) are converted to ASCII characters using the CHAR command.

Some of the measurements from the interface are sent over a series of two or more characters. In this case, each data byte is converted to a binary number, the two numbers are combined, and the result is converted to an integer. HP 48 Program 1 shows how the HP 48 obtains a value of 15,729 from the LabWorks interface counter:

| Line # | HP 48 Commands | HP 48-Displayed Result |
|--------|-------------------|------------------------|
| 1 | 16 STWS | |
| 2 | "C" XMIT DROP | |
| 3 | 1 SRECV DROP | "q" |
| 4 | NUM | 113 |
| 5 | R→ B | 01110001 |
| 6 | 1 SRECV DROP | "=" |
| 7 | NUM | 61 |
| 8 | R→ B | 00111101 |
| 9 | 1 8 START SL NEXT | 0011110100000000 |
| 10 | OR | 0011110101110001 |
| 11 | B→ R | 15,729 |

HP 48 Program 1. Reading the LabWorks counter.

(Note: HP 48 programs do not use numbered lines. The line numbers listed here are for reference purposes only.)

The first line of the program sets the maximum size of the binary numbers to 16 bits, and no value is returned to acknowledge this action. In lines 2 and 3, the calculator sends a character to request a counter reading and receives the first data character. The DROP command after each XMIT and SRECV removes a number 1 from the HP 48's data stack. The 1 is returned when a character is successfully sent or received and is not useful for any calculations. Line 4 converts the first data character to a decimal number,

and line 5 converts the decimal to binary. The second data character is received in line 6, and it is converted to a decimal, then binary number in lines 7 and 8. Line 9 shifts the second binary number eight digits to the left. Line 10 combines the binary number generated in line 5 with the left-shifted binary in line 9. The result is a 16-bit binary number which is the counter value. Finally, line 11 converts the binary number to an integer. This process is illustrated in Figure 43.

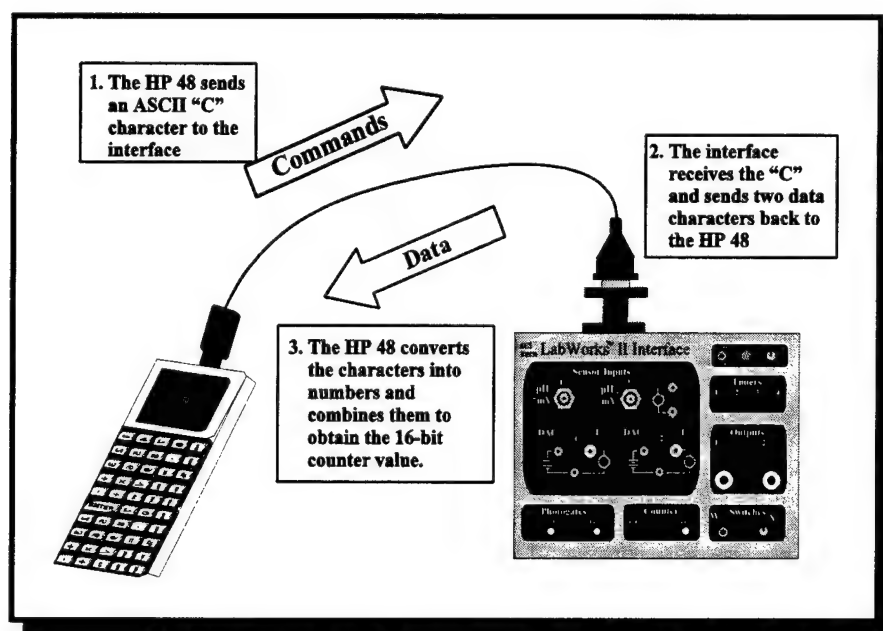


Figure 43. The HP 48 sends commands to the LabWorks interface and receives and displays the returned data.

Reading the Analog-to-Digital Converter

Obtaining data from the LabWorks interface's ADC is more complicated than reading digital information. The ADC takes an analog signal, such as from a thermistor, and converts it to a 12-bit binary number. The HP 48 receives this number in two bytes, like the counter, but only 12 bits of the incoming data are significant. The HP 48 uses a

subroutine called “ADC” that takes two values from the interface and combines them into a single real number. All HP 48 programs that read analog sensors use this subroutine.

The ADC subroutine requires that two numbers be placed on the HP 48’s number stack. The stack is memory storage that holds numbers waiting for mathematical operations. The size of the stack is only limited by calculator memory, but only the last four numbers on the stack are displayed. Figure 44 shows two numbers displayed on the stack. “ADC” uses the stack to manipulate the numbers while keeping the program as simple as possible.

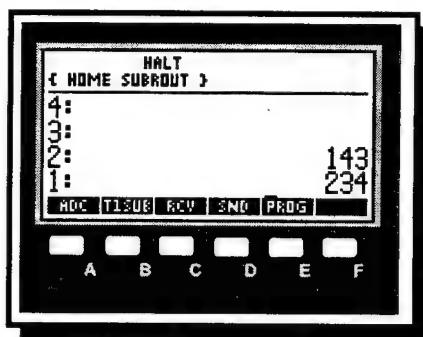


Figure 44. Two numbers displayed on the HP 48 stack.

If the two numbers displayed in Figure 44 were obtained from the LabWorks interface, HP 48 Program 2 shows how the ADC conversion is accomplished:

| Line # | HP 48 Commands | HP 48 Stack 1 | HP 48 Stack 2 |
|--------|-------------------|-----------------|-----------------|
| 1 | 12 STWS | 234 | 143 |
| 2 | R→ B | # 11101010b | 143 |
| 3 | 1 4 START SL NEXT | # 111010100000b | 143 |
| 4 | SWAP | 143 | # 111010100000b |

| | | | |
|---|-------------------|-----------------|-----------------|
| 5 | R → B | # 10001111b | # 111010100000b |
| 6 | 1 4 START SR NEXT | # 1000b | # 111010100000b |
| 7 | OR | # 111010101000b | |
| 8 | NEG | # 101011000 | |
| 9 | B → R | 344 | |

HP 48 Program 2. ADC conversion subroutine.

The first line of the program sets the maximum size of the binary numbers to 12 bits to accommodate the 12-bit ADC. No value is returned to the calculator display to acknowledge this action. In lines 2 and 3 the number in level one of the stack is converted to a binary number and shifted left four bits. Line 4 switches stack locations, temporarily storing the shifted binary value, and allowing the 143 value to be manipulated. Lines 5 and 6 convert the 143 to a binary value then shift it four bits to the right. Four bits are lost during this right shift, but the lost data is meaningless because the ADC has 12- and not 16-bit resolution. Finally, line 7 combines the two values on the stack using a binary OR command.

The HP 48 command NEG in line 8 takes the two's complement of a binary number. The values obtained by the interface's analog-to-digital converter use two's complement binary arithmetic. In this style of binary-to-integer conversion, the most significant binary digit is negative, and all others are positive.⁷⁸ This conversion program will return integer values ranging from -2048 to +2047. Line 9 converts this binary number to a real number.

Interface Calibration Constants. The values obtained from the ADC need to be converted again in order to be meaningful. These conversions occur using calibration constants stored in the LabWorks interface in a three-dimensional array. The calibration values reside in a 51×8 array, and four redundant copies of this array exist. The array is stored in the interface's erasable, programmable, read-only memory (EPROM). When the computer version of LabWorks begins, this array is copied into computer memory. This process was extremely difficult to duplicate using the HP 48. Therefore, calibration constants were experimentally derived and stored as variables in calculator memory.

Using the HP 48 to Read Electric Current

When the LabWorks interface reads electric current, its input is different from other devices using the ADC. Chapter 3 discussed the LabWorks II interface's autoranging current amplifier. This device sends a different set of values to the HP 48 than the other ADC devices in the interface. Because the electrical current amplifier is autoranging, three data bytes are sent to the HP 48, rather than the normal two. The third data byte is the current range code which tells the calculator the power of ten that needs to be applied to the data.

The command to read current from the interface is a single byte with bit 8 set to a value of 1. Bit 0 selects whether to read I1 or I2, and bit 1 selects fast or average ADC reading. The values of the five intermediate bits are not read by the interface. Table 5 summarizes the different commands used to read current from the LabWorks interface.

| Decimal Value | Binary Value | Input | ADC mode |
|---------------|--------------|-------|----------|
| 128 | 10000000 | I 1 | fast |
| 129 | 10000001 | I 1 | averaged |
| 130 | 10000010 | I 2 | fast |
| 131 | 10000011 | I 2 | averaged |

Table 5. LabWorks electric current reading commands.

The following subroutine, called I1SUB, is used with all HP 48 programs that need data from the LabWorks interface's I1 input. The subroutine calls ADC to convert the interface's analog-to-digital converter output to a real number. The SND command is a subroutine that combines CHR, XMIT, and DROP commands into a single function call. Likewise, RCV combines 1, SRECV, DROP, and NUM.

| Line # | HP 48 Commands | HP 48 Stack 1 | HP 48 Stack 2 | HP 48 Stack 3 |
|--------|-------------------------------------|---------------|---------------|---------------|
| 1 | 129 SND | | | |
| 2 | 1 3 START RCV NEXT | 24 | 234 | 143 |
| 3 | 3 ROLLD | 234 | 143 | 24 |
| 4 | ADC | 344 | 24 | |
| 5 | → x y | | | |
| 6 | CASE | | | |
| 7 | 'x == 0' THEN y 'I' STO END | | | |
| 8 | 'x == 8' THEN y 10 / 'I' STO END | | | |

| | | | | |
|----|---|-------|--|--|
| 9 | 'x == 16' THEN y 100 / 'I' STO END | | | |
| 10 | 'x == 24' THEN y 1000 / 'I' STO END | 0.344 | | |
| 11 | END I 1.221 * 'I' STO I | 0.420 | | |

HP 48 Program 3. Subroutine to read current from I1.

Line 1 sends the command to read from one of the current inputs. This command reads the I1 input in the averaged mode. Line 2 receives the two data bytes and the current range value from the interface. The possible current range values sent by the interface are 0, 8, 16, and 24 for I1, and 0, 32, 64, and 96 for I2.

Line 3 moves the current range byte from stack level 1 to stack level 3. The ADC subroutine is invoked in line 4 to convert the two data bytes, which are now on stack levels 1 and 2, into a real number. Line 5 saves the converted ADC number and the current range value into local variables x and y.

Lines 6 through 10 change the ADC number depending on the value of the current range value. The CASE command executes only the necessary line and ignores the rest. The multiplicative factor in line 11 is an empirical constant to give the current a value of 2048 at maximum output.

Advanced Experiment Control: Setting and Incrementing the DAC

Along with acquiring data from the LabWorks interface, the HP 48 can also set and increment voltage values to the interface's DAC. One experiment allows students to

determine the value of Planck's constant, and the procedure requires setting and incrementing a voltage value to the DAC. The HP 48 program that performs this experiment also accepts user input, matches this input with data from the interface, and saves this data in a two-dimensional array. This procedure is part of the experiment, "Spectroscopy—Experiments Using Visible Light," which is discussed in Chapter 9, and printed in its entirety in Appendix A. The chemistry behind calculating Planck's constant is discussed later in this chapter.

The process of sending values to the interface's 12-bit DAC is fairly complicated. A command byte is sent to the interface, along with three data bytes. Four bits (one nibble) from each data byte are incorporated into a single 12-bit value. The DAC uses this value to set a voltage between -2048 and +2048 millivolts, at one millivolt resolution. The HP 48 accomplishes this process by taking an integer, converting it to a binary number, dividing it into three parts, and sending these parts to the interface.

The program DAC1 shows how the HP 48 sends a value of 1,000 mV to DAC1:

| Line # | HP 48 Commands | HP 48 Stack 1 | HP 48 Stack 2 |
|--------|----------------|----------------|----------------|
| 1 | 2864 → m | | |
| 2 | 49 SND | | |
| 3 | m R→ B | #101100101101b | |
| 4 | 15 R→ B | #1111b | #101100101101b |
| 5 | AND | #1101b | |
| 6 | B→ R SND | | |
| 7 | m R→ B | #101100101101b | |

| | | | |
|----|-------------------|----------------|------------|
| 8 | 1 4 START SR NEXT | #10110010b | |
| 9 | 15 R→ B | #1111b | #10110010b |
| 10 | AND | #0010b | |
| 11 | B→ R SND | | |
| 12 | m R→ B | #101100101101b | |
| 13 | 1 8 START SR NEXT | #1011b | |
| 14 | B→ R SND | | |

HP 48 Program 4. Sending 1,000 mV to DAC1.

Line 1 of this program takes an integer and sends it to a local variable “m.” The value of the integer determines the value at which the DAC will be set. Incrementing or decrementing this integer will then increment or decrement the DAC. The relationship between m and the value of the DAC has been empirically determined to follow this equation:

$$\text{DAC value in mV} = 1.2242 m - 2506.5$$

Using this equation, the DAC could be set to 0 mV by using an m value equal to 2047, or set to -1,000 mV by making m equal to 1230.6.

Line 2 sends a decimal 49 to the interface, which is the equivalent to an ASCII character 1, which is the interface command to set DAC1. The next three values sent to the interface will determine the value of the DAC.

Lines 3 through 5 recall the variable m, convert it to a binary number, and isolate the last four bits using a bitwise AND function. This binary number is converted to a real number and sent to the interface in line 6. Lines 7 through 11 perform the same function, with the addition of shifting the binary number four places to the right and then

performing the bitwise AND. This bit shift isolates the center four bits so they may be converted to a real number and sent to the interface. Finally, lines 12 through 14 send the last four bits by shifting eight bits right, converting to a real number, and then sending this value to the interface. When the interface receives three data values after the 49, it sets the DAC to the appropriate value.

Using the Kelvin Sensor with the HP 48

The Kelvin sensor, described in Chapter 3 of this thesis, is an inexpensive, high-resolution temperature measuring device. The ability of the HP 48 to increment and decrement the LabWorks DAC and read current input makes the HP 48 capable of making temperature measurements using a Kelvin sensor. When reading a Kelvin sensor, the HP 48 has an advantage over a PC. Because the HP 48 can mathematically manipulate incoming data, input from the Kelvin sensor can be converted to an absolute temperature before it is displayed. In the PC version of LabWorks, the Kelvin sensor only displays differential temperature, which must be converted to absolute temperature after the experiment is finished.

Reading the Kelvin sensor requires two programs to run. The first program calibrates the sensor by finding the correct DAC voltage and storing the current offset and calibration temperature. The second program provides a continuous absolute temperature reading by reading the current produced by the Kelvin sensor, correcting for the current offset, and adding this value to the calibration temperature.

Calibrating the Kelvin Sensor. The Kelvin sensor calibration program is shown as HP Program 5.

| Line # | HP 48 Commands | HP 48-Displayed Result |
|--------|-------------------------------------|-------------------------------|
| 1 | 1824 'M' STO | |
| 2 | DO DDAC I1SUB UNTIL 'I \leq 0.8' | |
| 3 | END CLEAR CLLCD | |
| 4 | "ENTER CALIBRATION TEMPERATURE" " " | ENTER CALIBRATION TEMPERATURE |
| 5 | INPUT OBJ \rightarrow I - 'T' STO | |

HP 48 Program 5. Kelvin sensor calibration.

The actual program used to calibrate the Kelvin sensor contains commands that activate the appropriate LEDs on the front of the LabWorks interface. Those commands are not included in the HP 48 Program listing. In addition, very little feedback is given to users while this program is running, and the only necessary input is the actual temperature of the calibration solution. This program calibrates using either Kelvin or Celsius scale, based on the Kelvin sensor's response of one microamp of current per degree Kelvin change. Fahrenheit temperature could be used, but the conversion from Fahrenheit to Celsius must be programmed into the HP 48.

Reading the Kelvin Sensor. Once the Kelvin sensor is calibrated, the program used to read the sensor is simple. This program is listed in HP 48 Program 6:

| Line # | HP 48 Commands | HP 48-Displayed Result |
|--------|---------------------|------------------------|
| 1 | DO | |
| 2 | I1SUB T + | 25.003 |
| 3 | "Temp" → TAG 2 DISP | TEMP: 25.003 |
| 4 | UNTIL KEY END | |

HP 48 Program 6. Reading the Kelvin sensor.

The DO ... WHILE in lines 1 and 4 form an indefinite loop that causes this program to execute until the user presses a key. Line 2 reads current from I1 and adds this value to the global variable T that was created during the kelvin sensor calibration. Line 3 attaches a label to the value and displays it on the calculator screen.

Illuminating Interface Light-Emitting Diodes (LEDs)

Another benefit of the LabWorks system is the feedback that users get directly from the interface. LEDs located above each sensor input illuminate when that sensor is acquiring data. The HP 48 commands the interface to light LEDs by writing specific values to the interface memory. The write command, given by an ASCII W, is followed by two more characters which designate the memory address and the value that address will assume.

There are 16 sensor LEDs, plus two output LEDs. Three memory addresses control the illumination and extinction of these 18 lights. Each memory address is 8 bits wide, and each bit controls a single LED. Setting a bit to 0 illuminates an LED, while setting it to 1 turns the LED off. Table 6 shows the memory addresses and the specific bits manipulated to turn each LED on and off.

| Memory address | Bits set to turn LEDs on and off | | | | | | | |
|----------------|----------------------------------|----|------|------|------|------|-----|-----|
| 32 | SwW | V | I2 | I1 | DAC2 | DAC1 | pH2 | pH1 |
| 33 | T4 | T3 | T2 | T1 | CNTR | PG2 | PG1 | SwX |
| 34 | | | OUT2 | OUT1 | | | | |

Table 6. Memory addresses and bit settings to illuminate LabWorks interface LEDs.

For example, sending a 255 (11111111) to any of these three addresses turns all LEDs at that address off, while sending a 0 turns them all on. HP 48 Program 7 turns all LEDs on, off, then illuminates only the LEDs for DAC1-I1. There is no calculator output for this program; the interface itself provides the necessary feedback.

| Line # | HP 48 Commands |
|--------|-----------------------|
| 1 | 87 SND 32 SND 0 SND |
| 2 | 87 SND 33 SND 0 SND |
| 3 | 87 SND 34 SND 0 SND |
| 4 | 87 SND 32 SND 255 SND |
| 5 | 87 SND 33 SND 255 SND |
| 6 | 87 SND 34 SND 255 SND |
| 7 | 87 SND 32 SND 235 SND |

HP 48 Program 7. LabWorks LED Control.

Lines 1 through 3 turn on all LEDs by setting all address bits to 0. Lines 4 through 6 turn on all LEDs by setting all address bits to 1. Line 7 sends a value of 235 (binary 11101011) to memory address 32. Table 6 shows that the zeros in the binary 235 illuminate LEDs for I1 and DAC1.

Experiment Design Using the HP 48

One of the advantages of using the LabWorks interface and software is that this system allows users to easily build their own data acquisition programs. The HP 48 software and display abilities cannot match the flexibility and power of the LabWorks for Windows 95 software, but the capability for users to design their own experiments does exist.

The HP 48 experiment builder is based on the principle behind the LabWorks EZ Program, which was discussed earlier in this chapter. Users select sensor inputs from two menus, and can select single- or dual-input data collection modes. Using the same principle, the HP 48 experiment design program

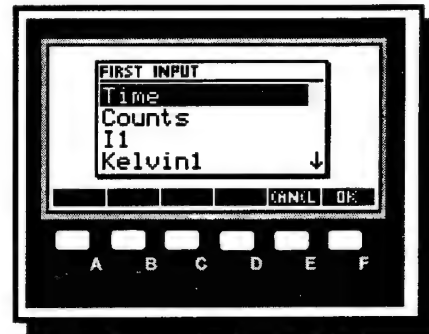


Figure 45. First HP 48 EZ Program screen.

presents users with two selection screens. After starting the program, users see the first sensor selection screen, shown in Figure 45. Users scroll through the sensor selection list using the calculator's up and down keys (\blacktriangle and \blacktriangledown), then make their selections by pressing "OK" (\square).

When the first sensor is chosen, the second selection screen, shown in Figure 46, appears. Users choose the sensor from the second list the same way

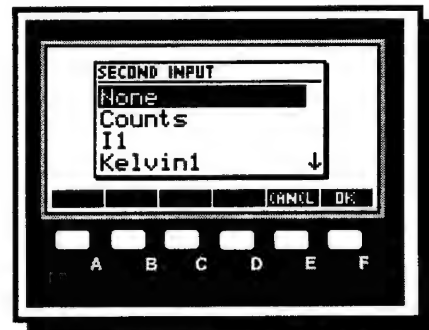


Figure 46. Second HP 48 EZ Program screen.

as the first list. Pressing "OK" a second time launches a data acquisition program using the sensor or sensors specified.

The HP 48 experiment design program, EZPRO, differs from the EZ Program used in LabWorks for Windows 95. In LabWorks for Windows 95, the EZ Program saves a series of commands in a file with an .EXP extension. Rather than creating a data acquisition program from scratch, HP 48 EZ Program applies the user selections to open a program that already exists in calculator memory.

Table 7 shows the choices available for the first and second inputs. In the HP 48 EZ Program, each choice is assigned a numeric value, and combinations are evaluated by CASE statements to select the correct program. Given this number of choices, potentially 32 data

| First Input | Second Input |
|-------------|--------------|
| Timer | None |
| Counts | Counts |
| I1 | I1 |
| Kelvin1 | Kelvin1 |
| pH1 | pH1 |

Table 7. Sensor choices for HP 48 experiment design.

acquisition programs can be launched. Some combinations, such as measuring counts for both first and second inputs, cannot be measured by the interface. If one of these trivial combinations are selected, the error screen shown in Figure 46 is displayed. Twelve programs are currently implemented, covering sensor combinations most likely to be used in introductory chemistry laboratories. Figure 47 shows the HP programs that can be implemented using EZ Program:

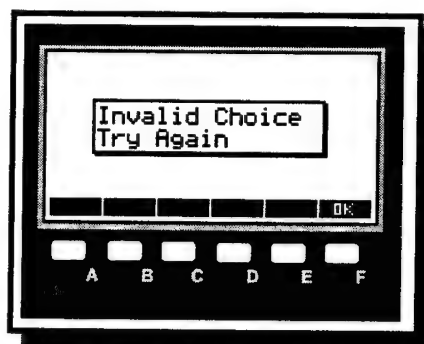


Figure 47. HP 48 EZ Program error screen.

| <u>First Sensor</u> | <u>Second Sensor</u> |
|---------------------|----------------------|
| Timer | None |
| Counts | None |
| I1 | None |
| Kelvin1 | None |
| pH1 | None |
| Timer | Counts |
| Timer | I1 |
| Timer | Kelvin1 |
| Timer | pH1 |
| Counts | pH1 |
| Counts | Kelvin1 |
| Counts | I1 |

Figure 48. HP 48 programs that can be implemented using EZPRO.

The command listing for EZPRO is given in Appendix B.

Future HP 48 Work

Future projects should include expanding the student experiment design capability of the HP 48. It might also be possible to use TI calculators for LabWorks interface control, a project that will require cooperation from Texas Instruments Corporation. The immense popularity of TI calculators with teachers and students may make this formidable task worthwhile.

Experimentally Determining the Value of Planck's Constant

The process of calculating Planck's constant in student laboratories began as a demonstration program in which students used different-colored LEDs to show that shorter wavelength light requires a higher excitation energy (Figure 49).⁷⁹

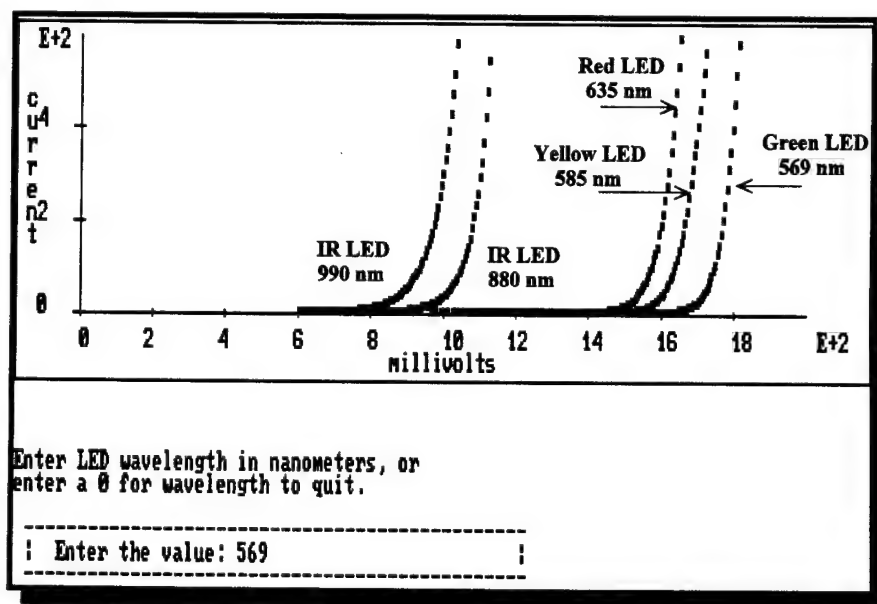


Figure 49. Graph of Planck's constant data acquisition. Shorter wavelength LEDs require higher excitation energies.

Excitation voltage is incremented in one millivolt steps using the LabWorks DAC. Once the band gap energy is reached, electrical current flows through the circuit and the LED illuminates. See Figure 50. Higher energy LED colors such as green and yellow have larger band gaps and require more excitation voltage than the lower energy colors such as red and infrared.

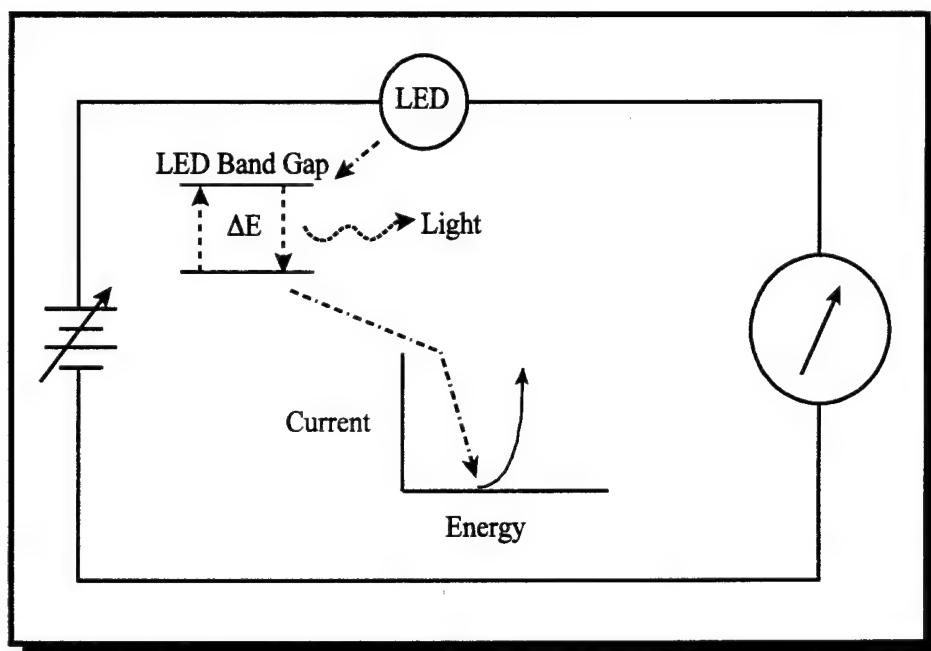


Figure 50. The band gap energy of an LED can be determined by applying a gradually increasing voltage and observing the point at which current begins to flow.

To make this experiment quantitative, the LED wavelength and the voltage required to obtain one microampere of current were saved for each LED. When this data was plotted, a downward-sloping straight line resulted. Converting LED wavelength to frequency and excitation voltage to joules resulted in an upward-sloping straight line with a slope very close in value to Planck's constant (Figure 51).⁸⁰

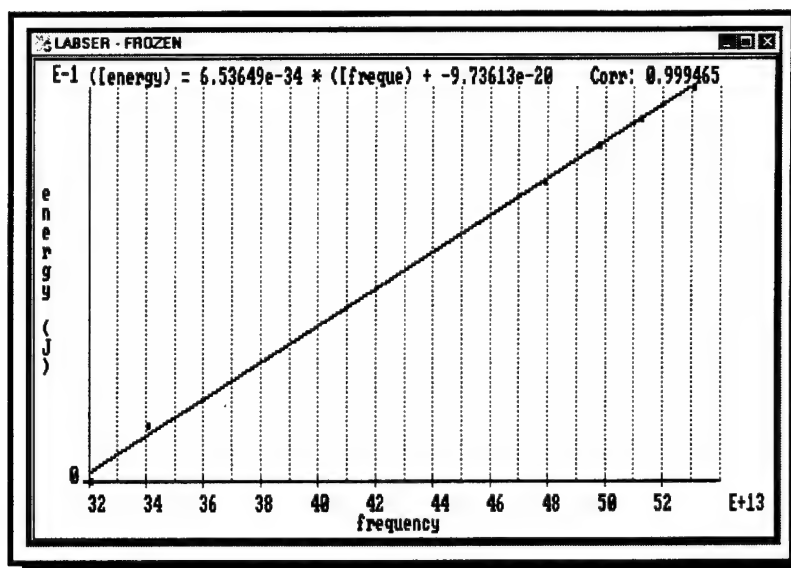


Figure 51. Graph of energy versus frequency for Planck data. The slope of the line of is very close to Planck's constant.

Determining Planck's Constant Using the HP 48

Originally, the Planck's constant experiment was performed using the different-colored LEDs, the LabWorks interface, and a computer running the MS-DOS version of the LabWorks software. Because the HP 48 can increment the LabWorks interface's DAC and read electric current, this same experiment can be performed using the HP 48 instead of a computer. The procedures for calculating Planck's constant using this equipment is divided into three parts: initialize, acquire data, and analyze. Students run a separate HP 48 program for each part.

To initialize the system, students run the program, PLINI (PLanck INItialize), shown in HP 48 Program 8. This program illuminates interface lights and resets the data array:

| Line # | HP 48 Commands |
|--------|-----------------------|
| 1 | 87 SND 32 SND 235 SND |
| 2 | 0 0 {1 2} → ARRY |
| 3 | 'DATA' STO |

HP 48 Program 8. Planck initialization program.

Line 1 illuminates the I1 and DAC1 LEDs, while lines 2 and 3 set a 1-row by 2-column data array named DATA. The "0 0" is a placeholder necessary to create the array, and will be deleted by the program ANLZ. No output is given in the calculator display when this program runs.

The data acquisition program, PLNK, prompts users for LED wavelength, converts this nanometer wavelength value to frequency, and then stores it. Figure 52



Figure 52. PLNK LED wavelength entry.

shows the calculator screen that prompts users to enter LED wavelength. The program next sets the DAC to 0.5 volts, and begins to increment the DAC while reading current from the LED. The current flowing through the LED will increase as the excitation

voltage increases. As the current and voltage increase, their values are shown on the calculator display. When the current reaches 0.1 microamps the DAC voltage is stored, and the voltage continues to increase so users may see the LED illuminate. When the current is greater than 2000 microamps, the program stops displaying current and voltage. The voltage value taken at 0.1 microamp is converted to joules, and frequency and energy information is saved in a data array. Another LED is connected to the interface, and the process is repeated for every LED. The frequency and energy values for each LED are added to the data array. The program itself is fairly complex, and is shown fully in Appendix B.

The final program, ANLZ (Analyze), performs a linear regression on the data array and displays the slope, intercept, and correlation coefficient of the data, as shown in Figure 53. ANLZ uses the inherent mathematical capability of the HP 48 to find the linear regression information for the Planck data. ANLZ is shown as HP 48 Program 9.

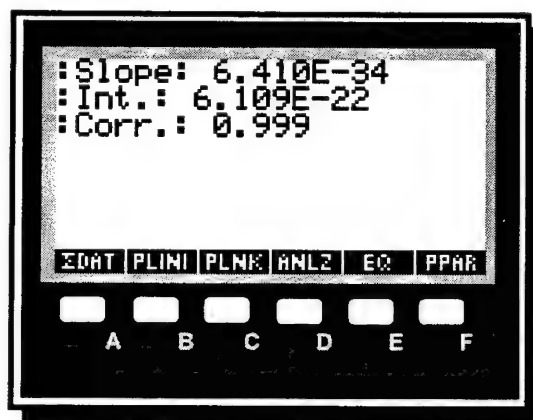


Figure 53. Slope, intercept, and correlation information for Planck data.

| Line # | HP 48 Commands |
|--------|---|
| 1 | DATA 1 ROW- DROP STO Σ |
| 2 | LR |
| 3 | 1 DISP DTAG "Int." \rightarrow TAG 2 DISP |
| 4 | CORR "Corr." \rightarrow TAG 3 DISP |
| 5 | 7 FREEZE |

HP 48 Program 9. Planck data analysis program.

Line 1 calls the array DATA, deletes the "0 0" placeholder that was used to create the data array in PLINI, and stores the data in a special analytical array, Σ DAT using the HP 48 command STO Σ . Line 2 executes the HP 48 linear regression command to find the slope and y-intercept of the data. Line 3 formats and displays the slope and intercept. Line 4 runs the HP 48 correlation coefficient command and displays this result. Line 5 freezes the calculator display to keep the information on the screen.

Other Experimental Work Involving Planck's Constant

While calculating Planck's constant is an experiment performed primarily in introductory chemistry laboratories, parts of this experiment can be explored on a much deeper level. One aspect of this experiment that could be explored is the y-intercept of the energy-versus-frequency line. Ideally, this intercept should be zero. While it is a very small number and very close to zero, its value is significant because the slope of the line is so small.

This experiment, in essence, is the photoelectric effect, but in reverse. Rather than photons striking a metal plate to cause the ejection of electrons, electron flow

through the diode is liberating photons. The y-intercept of the energy-versus-frequency line, therefore, can be thought of as the work function of the diode material.

To test the effect of current threshold on the slope and intercept, this experiment was run with different current thresholds ranging from 0.1 to 1000 microamps of current. The experiment set-up included a LabWorks II interface connected to an HP 48GX calculator running the programs PLINI and PLNK. Six identical LEDs with wavelengths ranging from 990 nm to 560 nm were used for each experiment. The data arrays for each experiment performed were then downloaded to a computer and combined using Microsoft Excel. The results are provided in Table 8, and a graph of the different thresholds is shown in Figure 54.

The data shows that the smallest current threshold gives a slope closest to the accepted value of Planck's constant, but it also gives the y-intercept furthest from zero. The data with the largest threshold gives the y-intercept closest to zero, but has a value of Planck's constant furthest from the accepted value. The remaining current thresholds fall between these two values.

| wavelength (nm) | frequency (Hz) | Energy required for 0.1μA | Energy required for 0.5μA | Energy required for 1μA | Energy required for 5μA | Energy required for 10μA | Energy required for 50μA | Energy required for 100μA | Energy required for 500μA | Energy required for 1000μA |
|--------------------|-------------------|---------------------------------|---------------------------------|-------------------------------|-------------------------------|--------------------------------|--------------------------------|---------------------------------|---------------------------------|----------------------------------|
| 990 | 3.03E+14 | 8.45E-20 | 9.80E-20 | 1.04E-19 | 1.18E-19 | 1.25E-19 | 1.41E-19 | 1.49E-19 | 1.63E-19 | 1.68E-19 |
| 880 | 3.41E+14 | 9.35E-20 | 1.07E-19 | 1.12E-19 | 1.25E-19 | 1.32E-19 | 1.45E-19 | 1.51E-19 | 1.63E-19 | 1.67E-19 |
| 635 | 4.72E+14 | 1.96E-19 | 2.08E-19 | 2.14E-19 | 2.24E-19 | 2.29E-19 | 2.41E-19 | 2.47E-19 | 2.59E-19 | 2.65E-19 |
| 600 | 5.00E+14 | 2.10E-19 | 2.22E-19 | 2.27E-19 | 2.38E-19 | 2.43E-19 | 2.53E-19 | 2.57E-19 | 2.71E-19 | 2.78E-19 |
| 585 | 5.12E+14 | 2.16E-19 | 2.29E-19 | 2.34E-19 | 2.46E-19 | 2.51E-19 | 2.62E-19 | 2.67E-19 | 2.79E-19 | 2.84E-19 |
| 560 | 5.35E+14 | 2.29E-19 | 2.41E-19 | 2.46E-19 | 2.57E-19 | 2.62E-19 | 2.72E-19 | 2.76E-19 | 2.87E-19 | 2.93E-19 |

Table 8. Planck data at different current thresholds.

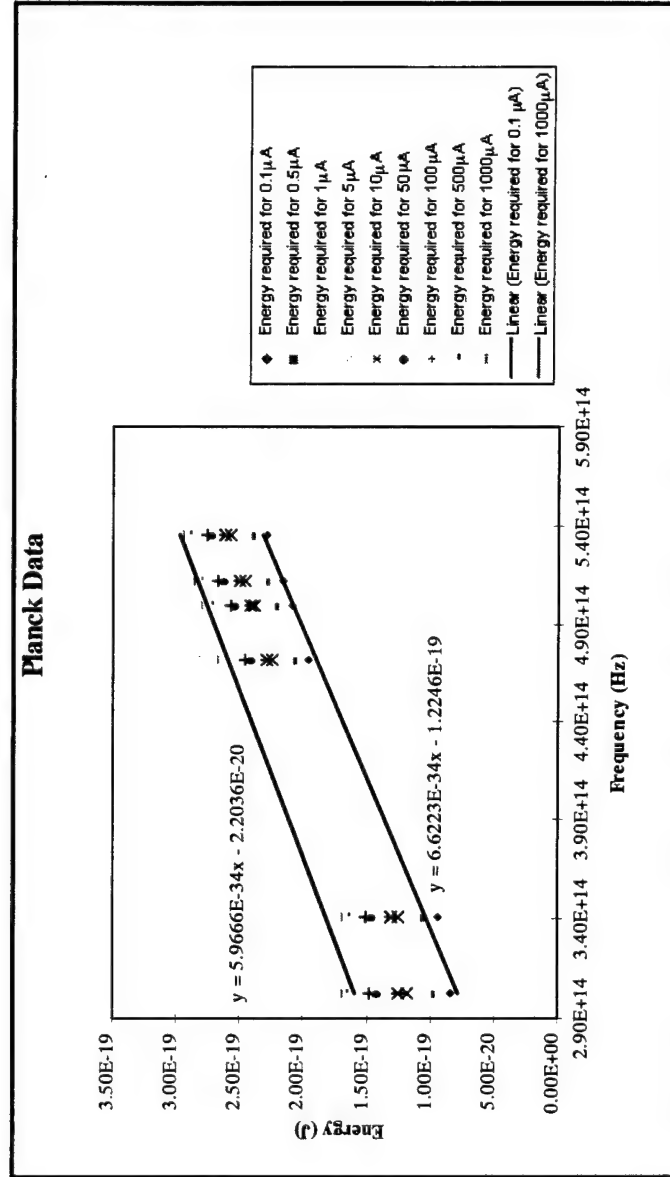


Figure 54. Graph of Planck data at different current thresholds. The linear regression data is shown for the highest and lowest current thresholds.

Conclusions

The software described in this chapter enables students to experience higher levels of learning according to Bloom's taxonomy. By making data acquisition hardware easier to use, students will be able to spend more time concentrating on the process of learning and less time trying to understand their laboratory equipment. LabWorks for Windows 95 and its utility, EZ Program, allow students to design their own experiments and achieve higher levels of learning. Finally, using the HP 48 to control the LabWorks interface allows students to access higher levels of learning in situations where it is impractical to use a personal computer.

CHAPTER 6

SOFTWARE INNOVATIONS: SIMULATIONS

The final software-related work presented in this thesis involves development and implementation of simulated experiments. Simulations are simplified representations of systems that, because of size, danger, or expense, are impractical to observe and measure directly. If properly designed, simulations can increase knowledge as well as provide a unique opportunity to involve students in the synthesis and evaluation levels of learning identified in Bloom's taxonomy. This chapter introduces three types of simulations, illustrates the application of each type of simulation both within and outside of the field of chemistry, and describes two educational simulations developed or implemented within this project.

The first simulation, Atomic Spectra, is an example of a single-pass simulation, in which students work at the knowledge and application levels identified by Bloom. The second simulation, the Energy-Environment Simulator, is an example of interactive simulation developed originally for the U.S. Atomic Energy Commission by John R. Amend and John F. Yegge. This model, which simulates the use of nonrenewable energy, broadens concepts taught in many college and university chemistry courses. Properly used, this simulation can place students in situations in which they must learn at

the synthesis and evaluation levels. This chapter identifies strategies that use this simulation to develop basic knowledge as well as synthesis and evaluation skills, and to determine whether these concepts and skills are being successfully applied. Figure 55 shows the relationship between software simulations, student actions in the laboratory, and higher levels of learning.

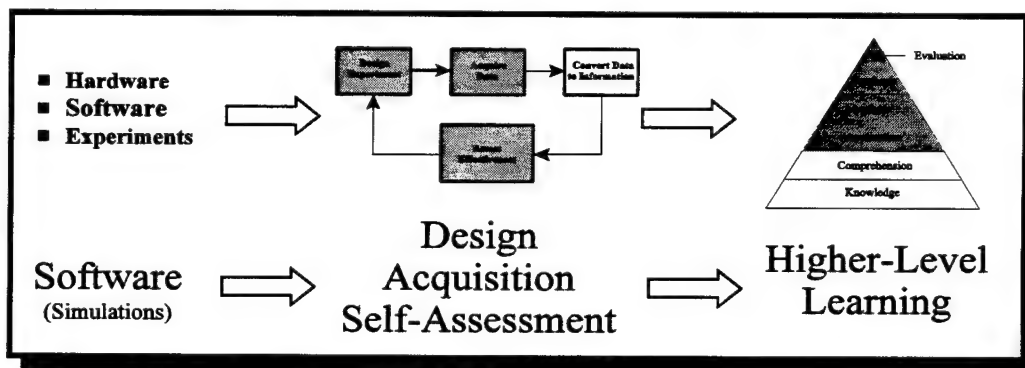


Figure 55. The link between simulation software and the project goal of higher-level learning. The self-assessment action available through simulations allows students to experience evaluation, which is the highest level of learning in Bloom's taxonomy.

Statement of Original Work

Atomic Spectra was written as a collaborative effort of the Amend research group. Development of the Energy-Environment Simulator program was not part of this project, but its application to introductory chemistry curricula and its relationship to Bloom's taxonomy are the original work of the author.

Types of Simulations

Simulations have been used to model complex systems for hundreds of years. There are many types of simulations, categorized according to complexity and degree of man and machine involvement. Three simulation types discussed in this chapter are single-pass, multiple-pass, and interactive.

Single-pass Simulations

The first and simplest simulations developed were single-pass simulations.⁸¹ These were astronomical charts used to navigate ships out of sight of land.⁸² The mathematical calculations required to develop star charts were tedious, but for the purpose of over-water navigation, the benefits outweighed the cost. Observations concerning the positions and movement of planets astronomical bodies were converted to mathematical models, and these models are used to predict the planets' and stars' future locations.

Knowing the positions of stars and planets allowed navigators to plot their positions on the ocean. Great wealth and knowledge were obtained using these simulations as tools. Figure 56 demonstrates the single-pass simulation process applied to navigational charts.

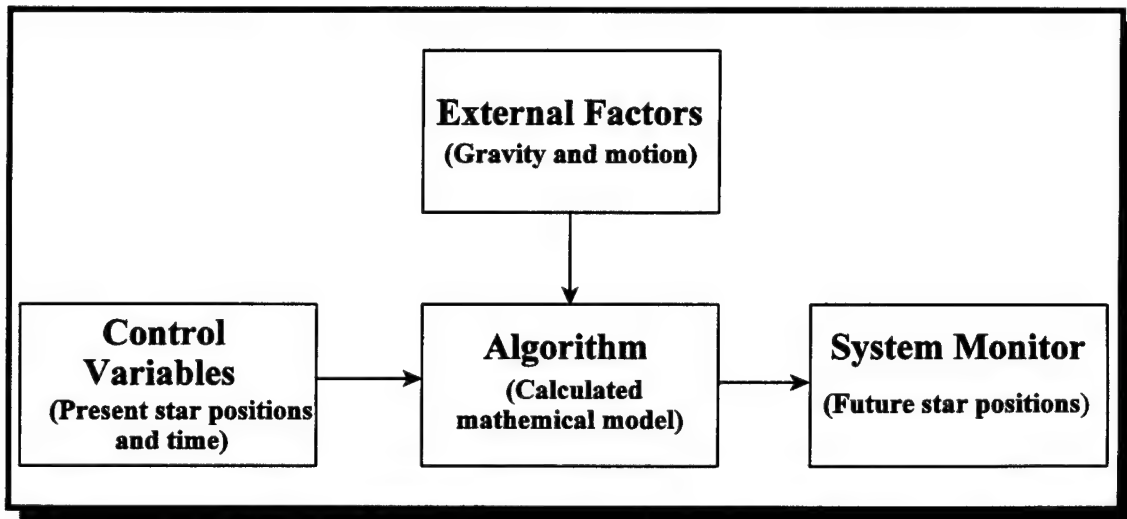


Figure 56. Single-pass simulation model applied to navigational star charts. Control variables and external forces are fed into a mathematical model that predicts future positions of stars and planets.

Multiple-Pass Simulations

During World War II, mechanical calculators became more common, allowing the mathematics required for simulations to be performed more easily. Analog computers were also built, enabling more complex simulations, such as aircraft automatic pilots and mechanical flight simulators. These complex simulations incorporated a feedback loop to correct deviations from a preprogrammed set of parameters. An automatic pilot is an example of a multiple-pass simulation, while a flight simulator is an interactive simulation. Both types of simulations are similar, but have important differences.

A multiple-pass simulation monitors input and uses a feedback system to constantly adjust control variables to obtain a desired response. An autopilot reads input from the aircraft instruments and moves the flight controls to maintain a preset course and

altitude. If a change in external conditions occurs, such as a change in wind direction blowing the aircraft off course, the actual heading is compared to the desired heading, and the computer initiates a course correction. The same process would occur for an altitude deviation. Figure 57 depicts a multiple-pass simulation model, using the autopilot description as an example.

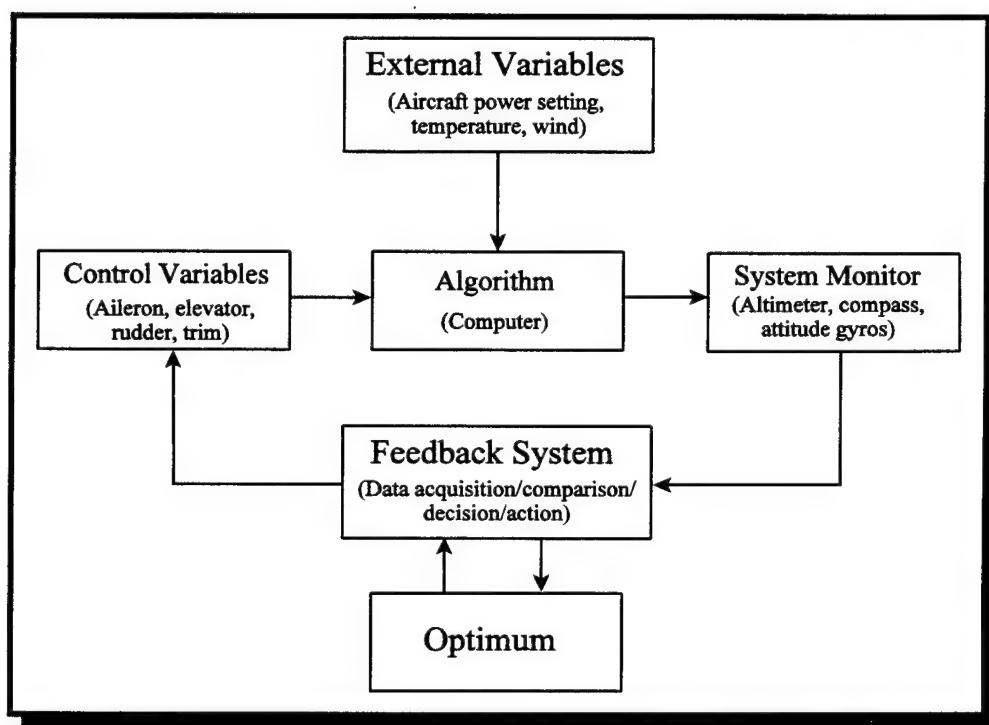


Figure 57. Multiple-pass simulation model applied to an autopilot. The feedback system makes constant corrections to keep the system at the desired state. In this example, the desired state is the correct altitude and heading.

Interactive Simulations

The last type of simulator type discussed is the interactive simulation. Interactive simulations operate in a similar manner to multiple-pass simulations, with two important differences: (1) the computer creates the operating parameters and environment; and (2)

interactive simulations require a human operator to provide feedback and corrective input. An example of a interactive simulation is a flight simulator. The computer sends commands to the cockpit instruments, mimicking the readings found in actual flight. The operator monitors the instruments and moves flight controls to obtain the desired flight conditions.

A flight simulator requires more computing power than an autopilot, because it is more difficult to create artificial flight conditions than it is to take readings from flight instruments. Figure 58 shows the model of an interactive simulation.

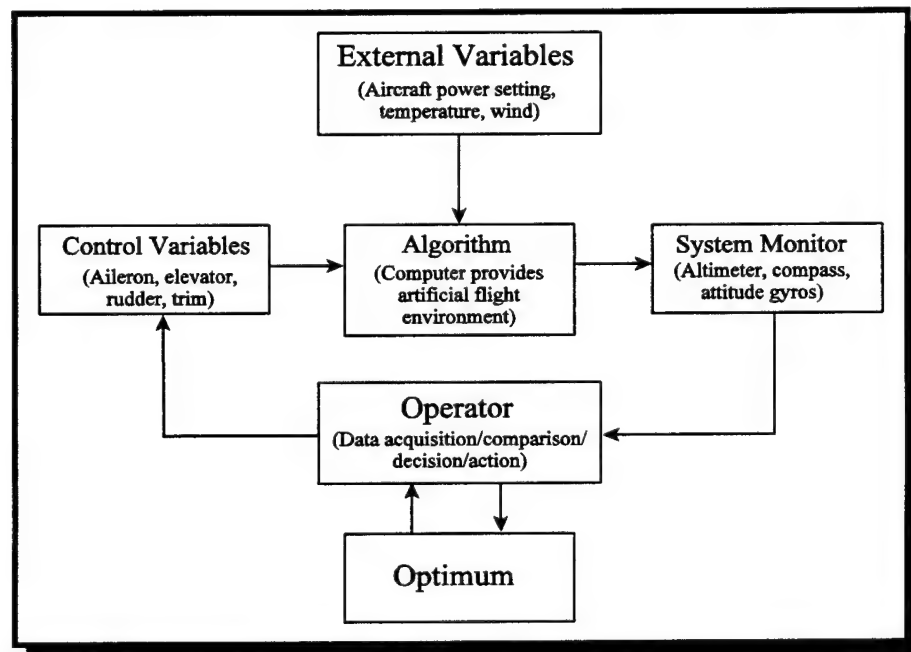


Figure 58. Interactive simulation model applied to a flight simulator. In an interactive simulation, the role of the computer is very different from its role in a multiple-pass simulation. The operator provides the feedback while the computer simulates the external environment.

In the 1960s and 1970s, simulation calculations were performed by mainframe digital computers, offering increased complexity and modeling of environments that were

previously untestable. Autopilots could control aircraft speed in addition to course and altitude, and could even perform automatic landings. Flight simulators using digital computers provided operators with high-resolution video information and hydraulic-powered motion sensations.⁸³

Flying is just one example of the evolving uses of simulations. In the late 1960s, Meadows et al. performed environmental studies using a computer simulation called *World3* that predicted dire results concerning our planet's use of resources. The findings from this simulation generated controversy, and were published in two best-selling books.^{84,85} The *World3* program was an extremely complex single-pass simulator. Once this simulator started, it accepted no further input from the operators and did not incorporate a self-adjusting feedback loop.

In addition to environmental and flight applications, mainframe simulations are widely used in chemistry. Chemical reactions, kinetics, quantum mechanical energy states, and solid and liquid states of matter are all approximated using computer modeling programs.⁸⁶⁻⁸⁸ The limited access available to mainframe computers restricts their use primarily to research applications and instruction.

Today, as personal computers become more powerful and inexpensive, simulations are becoming more accessible, while still maintaining their complexity and realism. This project incorporates a program similar to *World3* that runs on a personal computer and allows students to manipulate variables as the program runs. Microsoft Flight Simulator offers aircraft performance and visual effects that rival commercial and military flight simulators.⁸⁹ Chemistry simulations that required mainframe access five

years ago can now be run in educational settings at each laboratory station. It is this increased availability that allows students to use these tools and learn at the higher levels of Bloom's taxonomy.

Advantages of Using Computer Simulations

The main advantage of simulations is that they can explore environments that are too impractical, expensive, or dangerous to measure in real life. Malfunctioning nuclear power plants have been simulated to develop proper emergency procedures in case of an accident.⁹⁰ This data could never be obtained from even a scaled-down model. In another example, the *World3* simulation covered a period of time from the present through the year 2100. Only a simulation could increase the time scale enough to make the data useful. Finally, flight simulators allow student pilots to practice emergency procedures and low-visibility landings without risk to their personal safety or to their aircraft.⁹¹

In chemistry, the principle advantages of using computer simulations are increased safety and lower costs. In many schools and businesses, laboratories have a "cradle-to-grave" responsibility for purchase, storage, and disposal of hazardous chemicals. Educational laboratories can save huge sums by simulating reactions involving hazardous chemicals.

In the same way that flight simulators cannot replace actual flight training, chemistry simulations should not replace real chemical reactions in student laboratories. Even the best computer reaction simulations cannot exactly match the experience

students gain by mixing chemicals and observing the results of their actions. As a supplement to wet chemistry, however, simulations can maximize student experience while minimizing hazards and cost.

Project Simulation Programs

The computer programs examined in the next two sections allow students to safely and inexpensively learn at the upper levels of Bloom's taxonomy.

Atomic Spectra

The Atomic Spectra program was designed at Montana State University by the Amend research group. The program allows students to identify unknown elements by observing their emission spectra, and it includes aspects of both interactive and single-pass simulations. A human operator is required to run this simulation, but the program does not incorporate a feedback loop.

The previous method used to identify spectra displayed a slide of the unknown element's spectrum along with the spectrum of mercury.⁹² The slide also included a full visible spectrum as a reference; a sample is shown in Figure 59. Students traced the spectral lines for both the unknown element and mercury on a calibration sheet, shown in Figure 60. The wavelengths of the mercury spectrum were given, and students constructed a calibration graph that matched the scale values to mercury wavelength values (Figure 61). Using this calibration graph, students calculated the wavelength of the unknown spectrum, and matched those wavelengths to values given for various

elements. With this procedure, students could not only identify the unknown element, but apply the concept of calibration to spectral measurements.

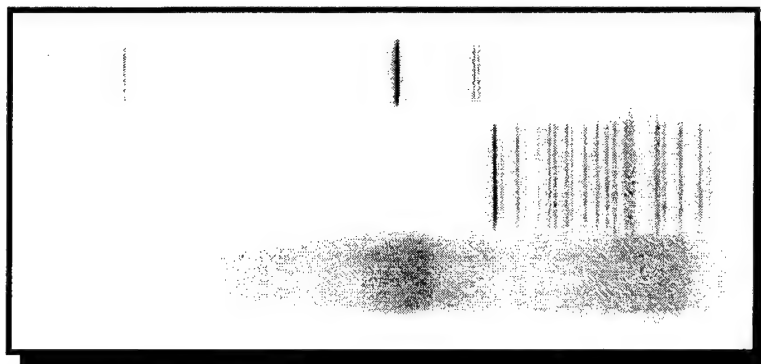


Figure 59. Sample spectra slide used to identify unknown elements. The slide shows the spectrum of mercury (top), the unknown (middle), and all visible colors (bottom).

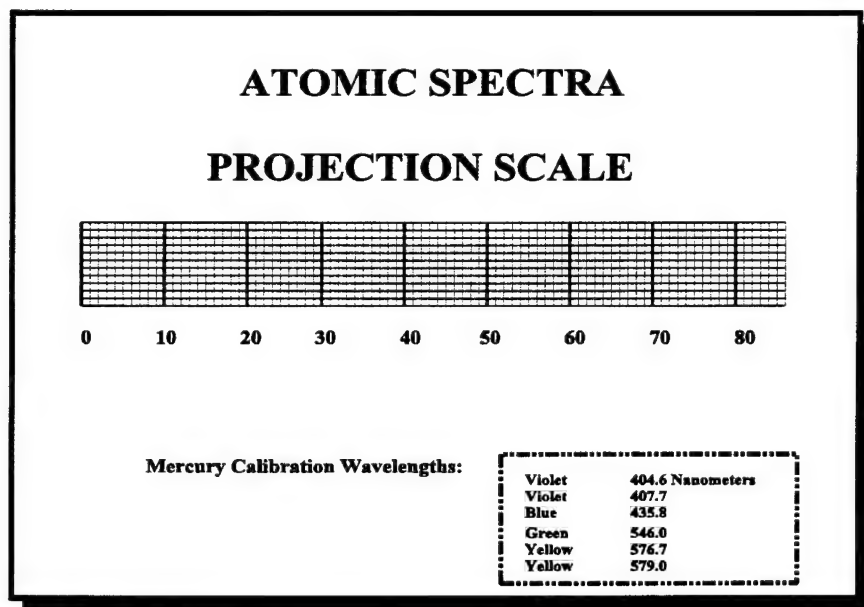


Figure 60. Atomic projection scale, with mercury wavelengths provided. Students use this scale to generate their calibration graphs.

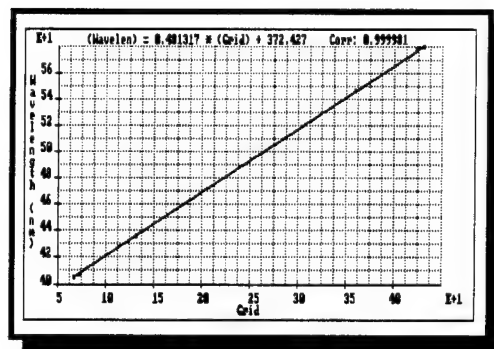


Figure 61. Calibration graph relating mercury wavelength to projection scale grid scale value.

The problem with this procedure was that the slide projectors required a high level of maintenance, both for experiment set-up and parts replacement. The Atomic Spectra program provides a much lower cost alternative. In addition to requiring less material than the slide projectors, Atomic Spectra is easier for students to use. Rather than move among the atomic projection scale, the spectra, and a graphing application, all of the objects necessary to perform the experiment are displayed on a single screen. Figure 62 shows a screen shot of Atomic Spectra.

To operate Atomic Spectra, students click on one of the unknown letters in the sample box, located in the upper right portion of the screen. The unknown letters are W, X, Y, or Z, with an H button used to examine the spectrum of hydrogen. Clicking on one of the unknown buttons brings up the spectrum of the unknown element placed underneath the mercury reference spectrum.

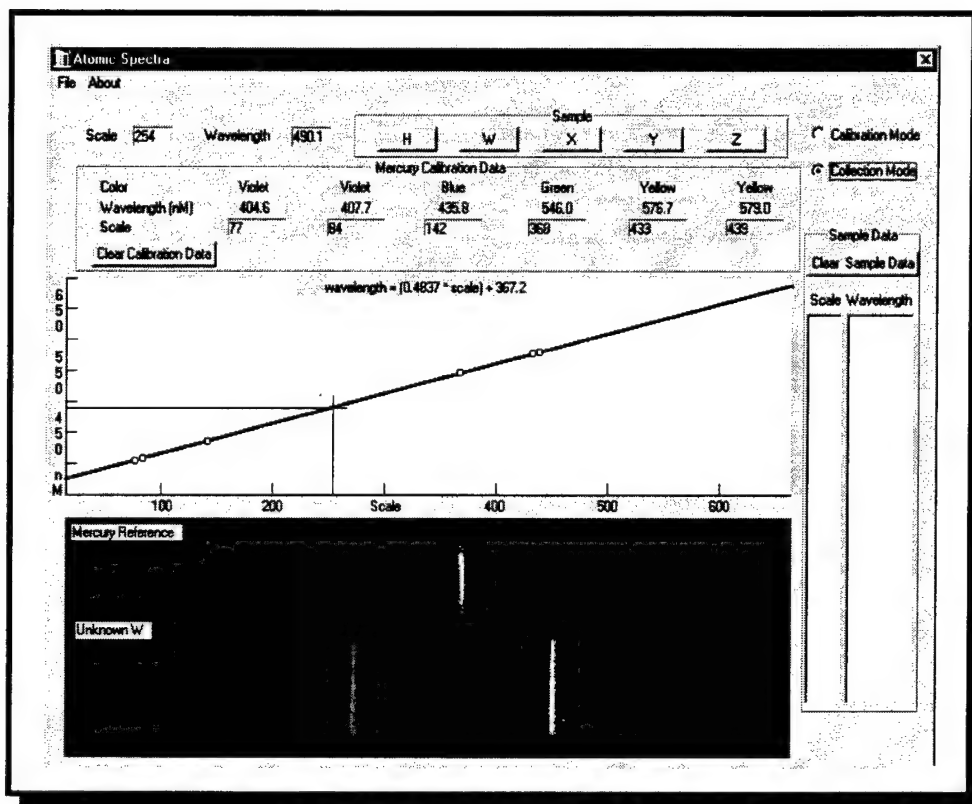


Figure 62. Atomic Spectra simulation screen. All the different procedures of the older experiment are performed in a single computer screen.

After displaying one of the unknowns, students turn their attention to the mercury calibration data box, located beneath the sample box. Students double click inside the open box under one of color columns. This inserts the word “Locate” inside the box. Next, students double click on the corresponding mercury spectral line to insert the calibration scale value in the box. When the scale value for the calibration line appears, the program automatically plots a scale/wavelength data point on the graph located between the mercury calibration data box and the unknown spectrum. When all six calibration lines are assigned scale values, students click on the collection mode button to

display the calibration line and its equation. A close-up of the mercury calibration data and linear equation is shown in Figure 63.

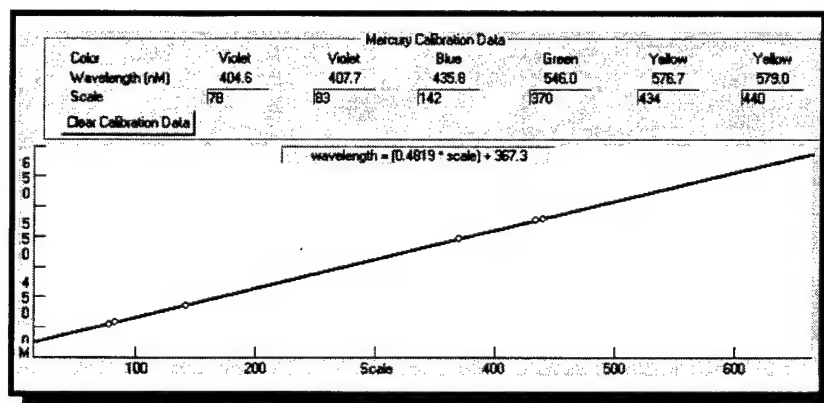


Figure 63. Close-up of the mercury calibration portion of the Atomic Spectra screen.

Once in the collection mode, students double click on each of the unknown spectral lines. Atomic Spectra then matches the scale value of the computer's spectral chart to the corresponding wavelength by using the calibration equation. The scale and wavelength values are then recorded in the box on the right side of the screen. To find the identity of the unknown, students compare the experimental wavelength values to reference values given in their experiment procedures. This procedure is much easier than the previous method of identifying unknown elements using spectra. In the same time required to identify one or two unknowns using the old procedure, students can identify all four unknown elements.

In addition to saving time and money, the properly executed exercises employing Atomic Spectra engage students at the application and synthesis levels of Bloom's taxonomy. The process of converting arbitrary scale values to meaningful units is a

process that is used throughout science. If students can understand and practice that concept in a controlled environment, they will find wet chemistry applications such as colorimetry easier to master. Chapter 9 discusses the use of Atomic Spectra in a laboratory experiment, and further explores the program's relationship to Bloom's taxonomy.

The user-friendliness of Atomic Spectra can be a detriment, as well as an advantage, however. Instructors need to be careful not to lose sight of the reasons for this exercise. With inadequate or improper instruction, it could degenerate into a pointless mouse-clicking activity. The philosophy behind proper instructor employment of technology is addressed in Chapter 11 of this thesis.

Energy-Environment Simulator

The Energy-Environment Simulator (EES) is an interactive simulation that runs on personal computers. The premise of this program is the same as *World3*: to model the world's use of nonrenewable resources. The EES is not as complex as *World3*, but the EES accepts user input while the simulation is running, making it a more active educational tool. Students using the EES will be making decisions that facilitate learning at the evaluation level of Bloom's taxonomy.

The Energy-Environment Simulator began not as a computer program, but as a suitcase-sized analog demonstration device. The output was comprised of light-emitting diodes and digital numeric readouts. User input was accomplished using dials on the simulator face or paddle switches connected to the device.

The underlying mathematical model and operating principles are the same for both the software and hardware versions of the EES. The simulator screen is shown in Figure 64. While it looks complex, it is divided into three main sections: energy sources, energy consumers, and energy pools. Figure 65 is a simplified outline of the EES screen, showing the interaction among these parts.

Six energy sources are included as part of the EES. Coal, oil, natural gas, and nuclear power are defined as nonrenewable resources, while hydroelectric and new technology are renewable resources. When supplies of the nonrenewable energy sources run out, they cannot be replaced. Hydroelectricity never runs out, but only a limited amount of power may be obtained from this source. The final energy source—new technology—represents renewable types of energy not yet commercially available. Solar, wind, geothermal, and biomass are examples of new technology. The initial useable supply of new technology is zero.

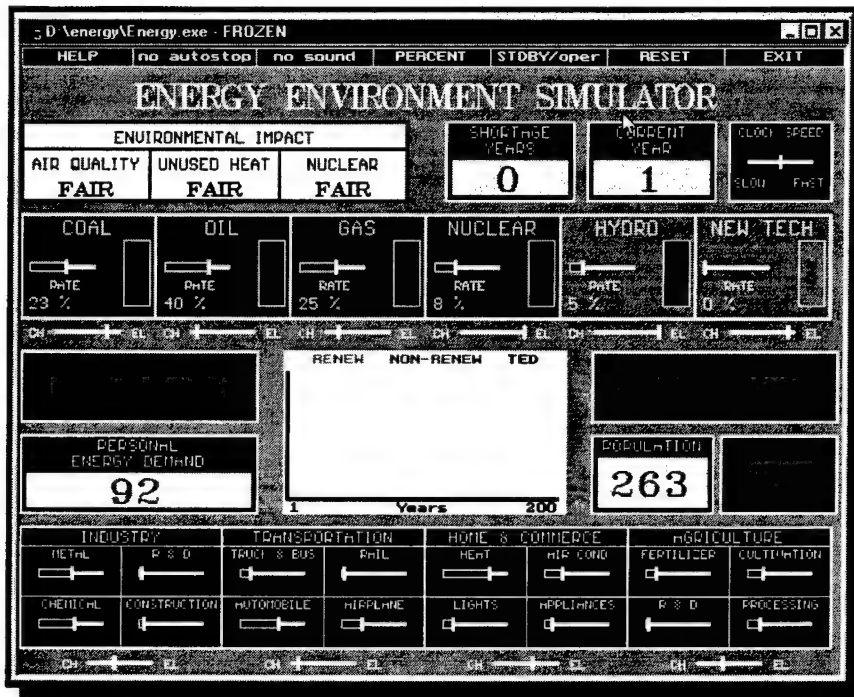


Figure 64. Energy-Environment Simulator main screen. This screen looks complicated, but is basically divided into energy sources, energy consumers, and energy pools.

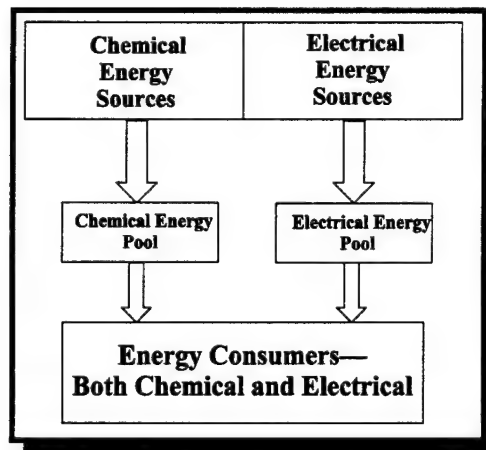


Figure 65. Simplified EES flow diagram. The chemical and electrical energy pools are supply/demand balance indicators. Students try to match decreasing resources against increasing demands.

Sixteen energy demands are divided into four groups: industry, transportation, home/commercial, and agriculture. Five of the individual demands influence simulator parameters beyond merely consuming energy. The four demands located in the agriculture category increase the food supply when their energy increases. Devoting energy to research and development (R&D) in the industry demand category increases the renewable energy source, new technology. Once available, new technology may be used as either chemical or electrical energy.

The chemical and electrical energy pools display the balance between energy production and use. If the energy pools show a shortage developing, the EES operator may increase energy production, decrease consumption, or both. Consequences of increased energy production include faster consumption of nonrenewable energy resources and adverse environmental impact through increased pollution.

World population can increase either linearly or exponentially, resulting in expanding energy demands that must be met by changes in energy production or consumption. Along with general energy demands such as heating, cooling, and transportation, energy must be devoted to food production. As the world population continues to get larger, more energy must be devoted to increasing the food supply.

When a shortage develops in either the energy pools or the food pool, the EES counts the year in which the shortage occurs as a shortage year. Users receive feedback in terms of the number of simulated years passed versus number of shortage years accrued. The simulator can also be programmed to either stop or elicit an audible computer signal when shortages occur.

Students operate the EES by clicking on STBY/OPER on the menu bar. Time passes as shown by the current year window. Energy production, consumption, and energy type (chemical or electrical) are adjusted by operating left- and right-moving slider switches. Students manage the simulation's energy resources and decide where to make cuts or increases in consumption and usage.

The simulator gives students feedback in the form of shortage years and total time elapsed. The feedback is presented in numerical format and by a graph displayed in the center of the simulator screen. The graph tracks the supplies of renewable and nonrenewable energy, total energy demand, and shortage years. A sample graph is shown in Figure 66.

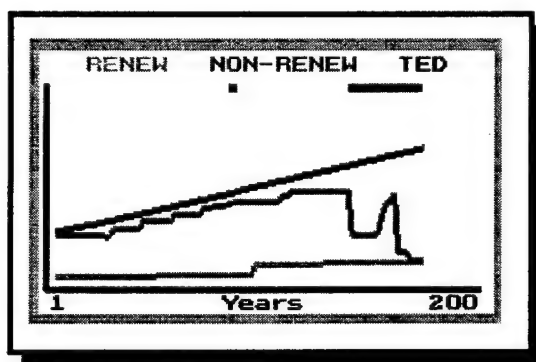


Figure 66. EES feedback graph. In this graph total energy demand continues to increase, while nonrenewable resources struggle to keep pace. Shortage years are shown as a bar across the top.

The feedback provided by the digital readouts and the graph gives students the opportunity to assess their own resource management strategies. This learning

experience matches the evaluation level of Bloom's taxonomy. Chapter 10 of this thesis discusses the laboratory experiment that incorporates the Energy-Environment Simulator.

Conclusions

Computer simulations allow students to quickly formulate, test, and revise their problem-solving strategies. Simulations save money, allowing students to perform experiments many times without wearing out experiment equipment. Also, the self-evaluation component of interactive simulations provides the unique ability to allow students to experience the highest levels of learning according to Bloom's taxonomy.

CHAPTER 7

THE EXPERIMENTS

Chapters 3 through 6 of this thesis have outlined hardware and software improvements designed to facilitate actions that increase student learning levels. All experiments developed in this project are rooted in the discovery-based (also called inquiry-based) learning model. This model works extremely well with the technology developed in this project, and with the upper learning levels of Bloom's taxonomy. This chapter outlines the discovery-based model for developing laboratory experiments, while chapters 8 through 10 integrate these tools into laboratory exercises that engage students in the thought processes necessary for higher learning.

Statement of Original Work

Inquiry-based teaching strategies are an ongoing goal of educational reform, and are used in all levels of science education.⁹³ While many variations of inquiry-based education exist, the model developed in this chapter is a product of the Amend research group.

The Discovery-based Model

While traditional laboratory exercises usually have students prove scientific concepts already taught in lecture, discovery-based learning allows students to experience the “Eureka!” sensation of uncovering those concepts for themselves.⁹⁴ When this occurs, the information becomes the students’ own ideas, rather than a directive from the professor. Carl Sagan described discovery-based learning this way:

At least every now and then, we should provide the evidence and let the reader draw his or her own conclusion. This converts obedient assimilation of new knowledge into personal discovery. When you make the finding yourself—even if you’re the last person on Earth to see the light—you never forget it.⁹⁵

The first recorded instance of discovery-based learning came from the Greek philosopher, Socrates. He is credited with the Socratic method of teaching, in which the instructor asks students leading questions, allowing the students themselves to deduce the concepts being taught.⁹⁶ Discovery-based learning has been successfully employed in college-level science laboratories, both in chemistry and physics.⁹⁷⁻⁹⁹ Discovery-based experiments that use technology as time-saving tools will allow students to learn at the higher levels of Bloom’s taxonomy.

The discovery-based experiment model is divided into four distinct areas: problem definition, experiment design, experiment performance, and application extension. Figure 67 shows how the model is implemented.

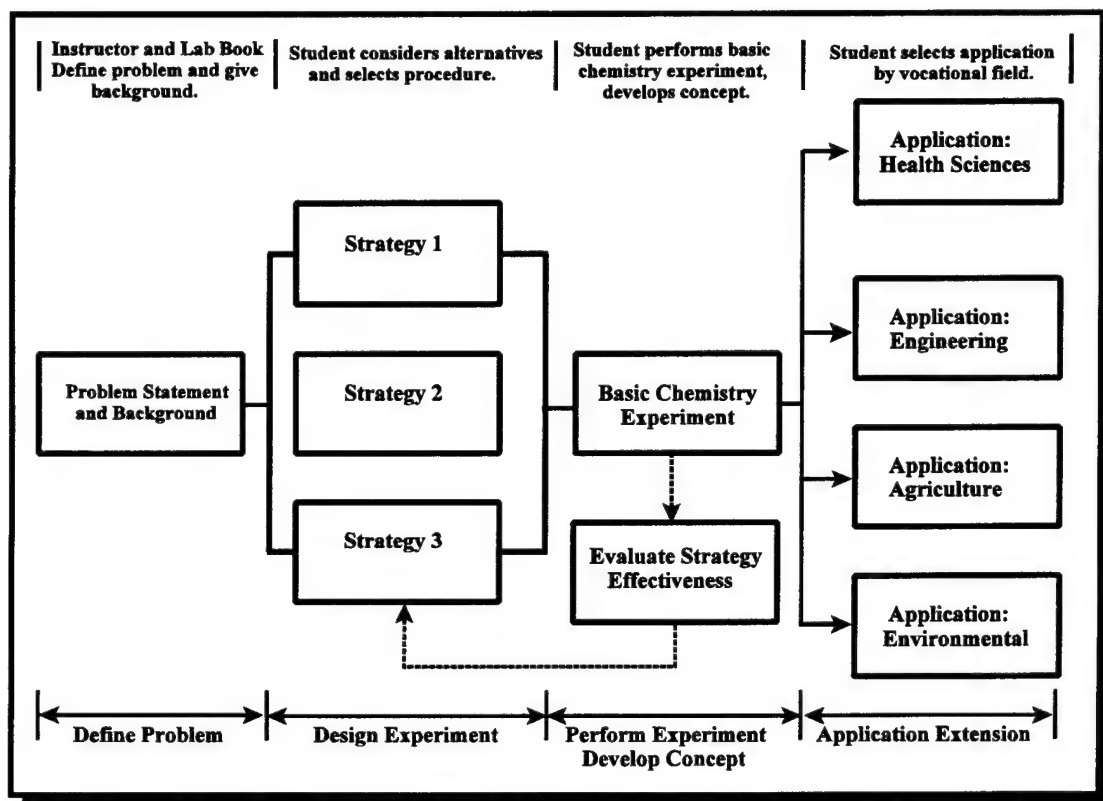


Figure 67. Discovery-based experiment outline. Students design experiments, evaluate the results of their decisions, and apply their designs to real-world problems.

In the first part of the experiment, the instructor and students use the laboratory textbook to define a chemistry-related problem and explore its significance to chemistry content. The chosen problem incorporates concepts covered in the lecture. Students consider several alternative data acquisition alternatives, then select the most appropriate experimental method. To develop the basic concept, all students will perform the same experiment.

If laboratory time permits, students may examine the effectiveness of their experiment design, make changes, and perform the basic experiment again. It is this

evaluation process that is the highest level of learning in Bloom's taxonomy, and most closely models actual scientific research. This model gives students the opportunity to initially fail, then overcome their setbacks to ultimately succeed.

To draw them further into the research experience, students will solve a problem in one of several areas related to their vocational interests. These application extensions to the experiment should try to reflect actual research being performed in each specific area. For example, biology and medicine are incorporating more elements of biochemistry every day. Agriculture and environmental science rely on complex chemical tests and computer-aided data-gathering techniques. These types of experiments may be cost-effectively performed by placing improved technology in student laboratories. In this way, students can be exposed to the type of scientific procedures they will perform in their major fields of study, as well as in their chosen professions.

The need for applications in experiments became imperative when the following student comment appeared in a Chemistry 132 laboratory report: "Over Spring Break I spent a week doctoring scoured calves and would find class much more interesting and worthwhile if I could see some applications in my field of study." This comment was unsolicited, and really brought to light the need to incorporate applications into experimental procedures whenever possible.

Experiment Units

This project includes five experiments that are grouped into three chemistry units (Figure 68). All of the experiments developed in this project are presented in their entirety in Appendix A.

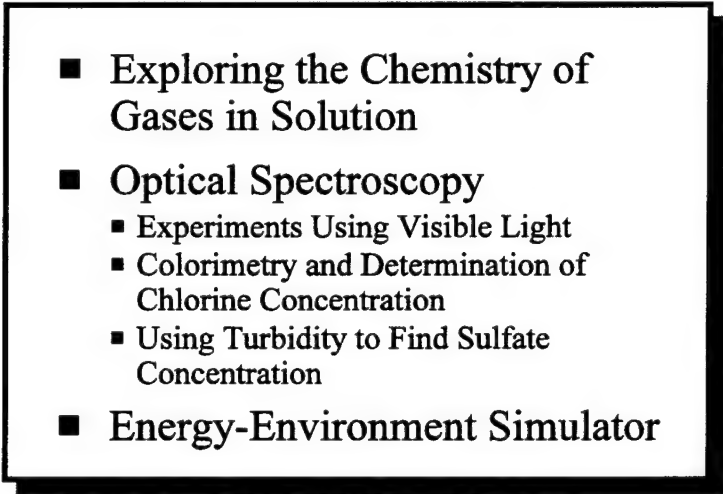
- 
- Exploring the Chemistry of Gases in Solution
 - Optical Spectroscopy
 - Experiments Using Visible Light
 - Colorimetry and Determination of Chlorine Concentration
 - Using Turbidity to Find Sulfate Concentration
 - Energy-Environment Simulator

Figure 68. Concept units and experiments in this project.

The first conceptual unit investigates the chemistry of dissolved gases in solution. In a single laboratory experiment, students combine various chemistry concepts with their own observations. The students then draw their own conclusions about what is causing a particular behavior, and apply these conclusions to a real-world scenario. The technological tools and the taxonomy learning levels applied to this experiment are discussed in detail in Chapter 8.

The next unit is comprised of three experiments that can either stand alone, or be used together in a block of instruction centered around optical spectroscopy. The first

experiment, "Spectroscopy—Experiments Using Visible Light," introduces the interaction of electromagnetic radiation with matter. The next experiment in this block, "Colorimetry and Determination of Chlorine Concentration," introduces the concepts of color formation and Beer's Law. In the final experiment of the unit, "Using Turbidity to Find Sulfate Ion Concentration," the concept of light scattering is introduced, providing another application of spectroscopy. The technological and taxonomical tools for these three experiments are covered in Chapter 9.

The final unit fuses different chemistry concepts into a single computer simulation exercise. Students make energy production and consumption decisions and evaluate the impact of these decisions on the world's environment and energy supplies. In order to accomplish this experiment, students must learn at the evaluation level of Bloom's taxonomy. The concepts in this experiment are explained in Chapter 10.

CHAPTER 8

EXPLORING THE CHEMISTRY OF GASES IN SOLUTION

“Exploring the Chemistry of Gases in Solution” is designed to allow students to experience the synthesis level of learning. Students are presented with a loosely defined problem and background bits of information that are seemingly unrelated to one another. The experimental procedures are fairly straightforward, but the conclusions that the students must draw require creativity and critical thinking.

Statement of Original Work

This experiment is an original product of this project. Its use of new technology and reliance on Bloom’s taxonomy makes it unique to introductory chemistry laboratories.

Experiment Description

In the background section of the experiment, students are given short explanations of various chemistry topics such as acids and bases, buffers, and the solubility of gases in water. This experiment is designed to be performed after students have been introduced to the associated concepts in chemistry lecture. Because of the higher-level learning that

is required to accomplish this experiment, students should already be familiar with these concepts at a fundamental level.

In the experimental procedures section, students measure the pH of carbonated water, cola, and lemon-line soda, and record the values on their data sheets. Next, they heat all these samples, and observe that the dissolved carbon dioxide gas leaves solution. Students then measure the pH of these samples again, noting how the pH of each sample changes. They must then explain the function of the dissolved CO_2 and why the pH increases for the carbonated water when CO_2 is released, but decreases when the gas is released from cola and lemon-lime soda.

Critical thinking plays a vital role in this experiment, as the same action, heating, makes the carbonated water's pH change differently than the cola's pH. The reaction of carbon dioxide with water and the properties of buffers are explained in the experiment, but students are not told what to expect from their experimental data. The supposed discrepancy is illustrated in Figure 69. Students may think their data is in error, and eventually they must accept that carbonate and bicarbonate ions caused by the dissolved CO_2 can act both as an acid and as a buffer, depending on the other chemicals that exist in solution.

This experiment demonstrates that gas solubility decreases as solution temperature increases, and this may also be counterintuitive to students. Once understood, however, students will be able to fully understand why raising the temperature of a lake or stream is a form of pollution and is damaging to the ecosystem.

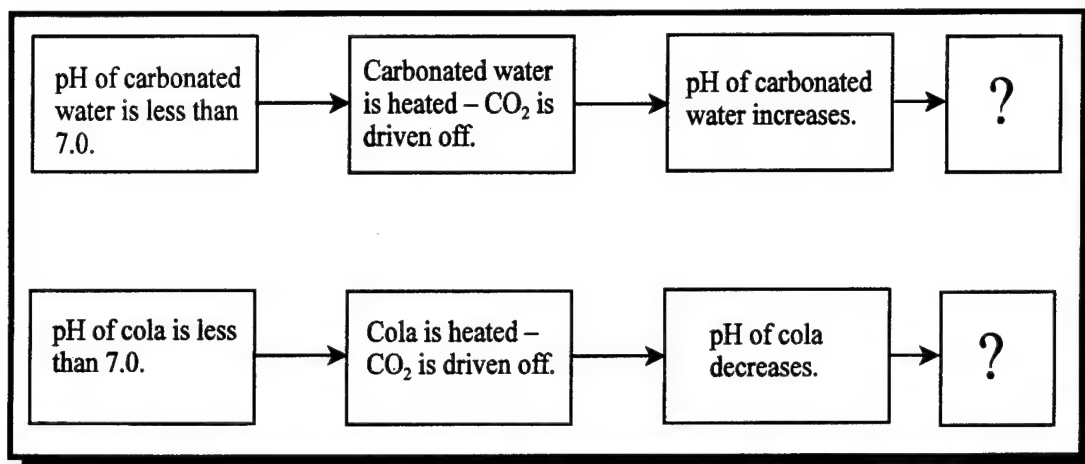


Figure 69. Activity/concept flow chart for “Exploring the Chemistry of Gases in Solution.” Heating both carbonated water and cola produces different pH changes. Students must explain why.

The experimental procedures are designed to accommodate pH measurements taken by an HP 48 calculator attached to the LabWorks interface, but any pH measuring device may be substituted. The innovations in this experiment are its abstract nature and the application problems listed at the end of the experiment. After performing the experimental procedures, students answer a series of application questions related to medicine, agriculture, or environmental science.

Concepts, Technology, and Bloom’s Taxonomy

Students should complete this experiment with a healthy understanding that if laboratory data does not always produce an expected result, the reason is not always experimental error. Technology used in this experiment and the low cost of materials (carbonated beverages) allow students opportunities to make multiple measurements to confirm the validity of their data. Once they complete this experiment, they will realize

that they have broken the mold of traditional experiments that are designed to prove principles already explained in class. The chemical principles, technological tools, and level of learning incorporated into this experiment are summarized in Table 9.


| Chemical Principles | Technology | Learning Level |
|--|--------------------|--|
| pH and acid concentration | HP 48 | Synthesis  |
| Chemical equilibrium and Le Chatlier's Principle | LabWorks Interface | |
| Temperature dependence of gas solubility | pH Probe | |

Table 9. Chemical principles, technology, and Bloom's taxonomy learning level associated with the experiment, "Exploring the Chemistry of Gases in Solution." These experiments require students to think at Bloom's synthesis level of learning.

CHAPTER 9

OPTICAL SPECTROSCOPY

The optical spectroscopy unit includes three experiments that build on each other to form one complete block of instruction. The first experiment in the unit provides background and introduces wave behavior and the ways in which electromagnetic radiation interacts with matter. The second experiment focuses the discussion of electromagnetic radiation on visible light and the formation of color. This experiment also introduces Beer's Law and applies this concept to colorimetry and finding the concentration of a unknown solution. The final experiment explores light scattering and introduces turbidimetry as an analytical method of determining water quality.

Each section in this chapter centers on a different experiment and shows how each experiment applies the hardware and software tools described in earlier chapters. The actions that the students perform to complete each experiment allow them to experience higher-level learning.

Statement of Original Work

The first experiment in this unit, "Spectroscopy—Experiments Using Visible Light," is an adaptation and extension of an experiment written for laboratories at

Montana State University.¹⁰⁰ The experiment was updated to include a revision of laboratory procedures, new figures, and consideration of learning according to Bloom's taxonomy.

The next experiment, "Colorimetry and Determination of Chlorine Concentration," is also an adaptation of an experiment that was previously used in introductory laboratories at Montana State University. The original experiment used colorimetry to find nitrate concentration in river water.¹⁰¹ The procedure for this experiment was changed to measure free chlorine in solution rather than nitrate ion concentration. New procedures, figures, and technology are also incorporated into this experiment.

The final experiment in the unit, "Using Turbidity to Find Sulfate Concentration," is an original product of this project. This experiment incorporates the LabWorks turbidimeter, and requires students to use simple nephelometry and ratio nephelometry. This is the first introductory experiment to incorporate these analytical techniques using inexpensive equipment.

Spectroscopy—Experiments Using Visible Light

Used in the context of the optical spectroscopy unit of instruction, the spectroscopy experiment is written to provide an introduction and background to students. This first look at electromagnetic radiation builds conceptual foundation, which will be extended and applied in the subsequent experiments in this unit.

To aid in students' exposure to higher learning levels, new technology is employed in two parts of the experiment. Students use the computer simulation program, Atomic Spectra, to identify unknown compounds by comparing the unknowns' spectra to the known spectrum of mercury. A detailed explanation of the Atomic Spectra simulation is provided in Chapter 6 of this thesis.

The second application of new technology in this experiment allows students to determine the value of Planck's constant using colored light-emitting diodes (LEDs). The LEDs attach to the LabWorks interface, which is controlled either by an HP 48 calculator or a personal computer. This process is discussed in depth in Chapter 5 of this thesis.

The theoretical nature of this experiment makes extension to applications difficult, but ample opportunity exists for group discussion and discovery-based learning. In one part of the experiment, students are presented with Bohr's planetary electron model and the visible spectrum of hydrogen. Again using Atomic Spectra, students compare the experimental spectral wavelengths to Bohr's theoretical calculations. Students may also use the Bohr equation to calculate the excited energy levels from which the light originated. The relative brightness of the hydrogen lines is also presented for student explanation, opening up the subject of probability and energy level occupation.

Concepts, Technology, and Bloom's Taxonomy

The chemistry principles, the technology employed, and the Bloom's taxonomy learning levels accessed by this experiment are summarized in Table 10.

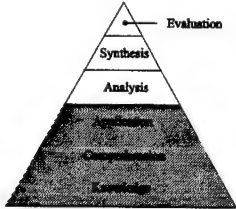
| Chemical Principles | Technology | Learning Level |
|---|---------------------------------|--|
| Wavelengths and frequencies of colors of the visible spectrum | HP 48 | Knowledge Comprehension Application  |
| Line spectra and band spectra | LabWorks Interface | |
| Experimental determination of Planck's constant | LabWorks wood block colorimeter | |
| Identification of unknown elements using their spectra | <i>Spectra</i> computer program | |
| Demonstration of Bohr's planetary electron model | | |

Table 10. Chemical principles, technology, and Bloom's taxonomy learning level associated with the experiment, "Spectroscopy—Experiments Using Visible Light." The introductory nature of this experiment builds a foundation of learning by requiring the use of knowledge, comprehension, and application learning levels. Higher levels of learning are developed by later experiments in this instruction unit.

Colorimetry and Determination of Chlorine Concentration

This experiment is a natural extension of the spectroscopy experiment. The previous version of this experiment required the addition of cadmium-containing dyes to a water sample to test for the presence of nitrate ions in solution. This procedure was complicated, the solutions were prone to contamination, and the NitraVer chemicals required hazardous waste disposal. In the new version of the experiment, students test for free chlorine using N,N-diethyl-p-phenylene diamine (DPD). DPD is an indicator that oxidizes in the presence of free chlorine to produce a red-colored solution.¹⁰² Figure 70

shows how the reaction of DPD with chlorine changes the indicator from a colorless molecule to a deep red. DPD is used commercially as a swimming pool testing chemical. The new procedure is single-step, and involves no hazardous materials.

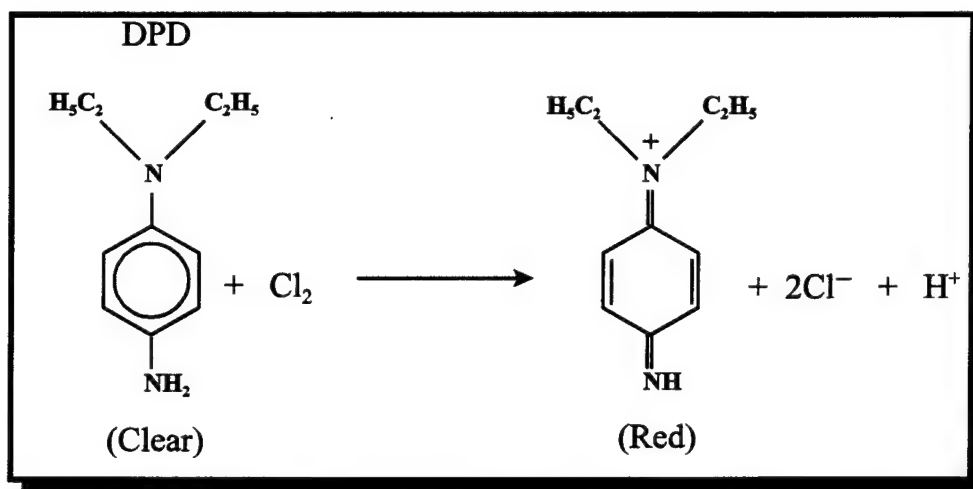


Figure 70. The reaction of DPD with free chlorine converts the molecule from colorless to a deep red. In the laboratory, this single-step reaction involves no hazardous chemicals.

This experiment uses the LabWorks interface and wood block colorimeter, shown in Figure 71. The experiment procedures employ the HP 48 calculator to send commands and receive data from the interface. The colorimeter uses phototransistors to send electrical current information to the HP 48 via the interface. The calculator converts this information to absorbance ($-\log[I/I_0]$), saves calibration information, and calculates the slope, intercept, and correlation of the calibration line. This experiment can also be performed using a personal computer controlling the LabWorks interface.

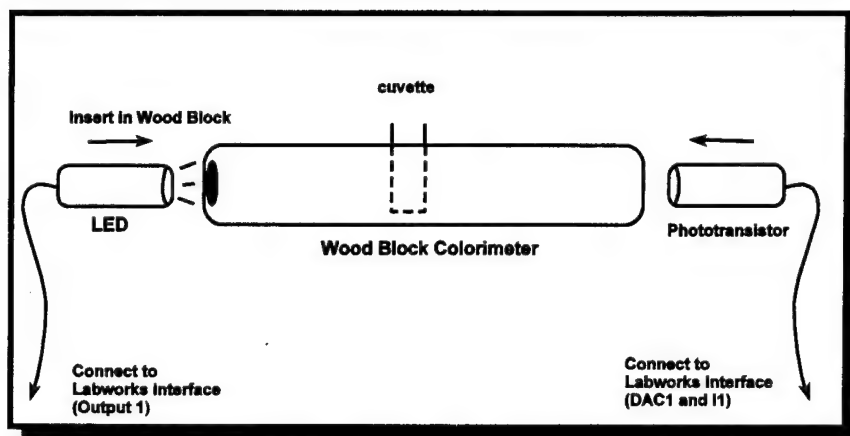


Figure 71. LabWorks colorimeter set-up.

When a solution of unknown concentration is measured, the calculator converts the unknown's percent transmittance signal to absorbance, and then uses the calibration equation to find the concentration. The use of technology simplifies this calibration process, allowing students to spend more time on chemistry concepts and experiment design.

The student procedure is divided into three parts: (1) design experiment/calibrate, (2) make measurements, and (3) analyze data. In the experiment design portion, students must determine the correct source light color by examining spectral charts of various colored solutions. Students are told that the DPD solution turns red in the presence of chlorine, and they must determine which colors of the visible spectrum are absorbed by a red solution. Figure 72 shows the spectral chart for a red solution.

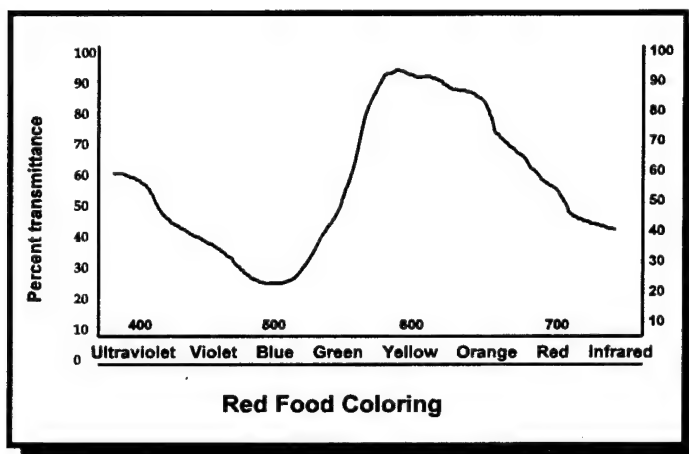


Figure 72. Spectral chart for a red-colored solution. Shorter wavelength light sources are absorbed better than longer wavelength sources.

From the background provided by the handout and chemistry lecture, students should be able to determine that shorter wavelength, sources such as green and blue, absorb much better than longer wavelength, sources such as orange or red.

After determining the color of their source light, students calibrate their colorimeters using the HP 48 Program, COCAL (Colorimeter CALibration). This program instructs students to insert a cuvette of distilled water into the colorimeter and calibrate (Figure 73).

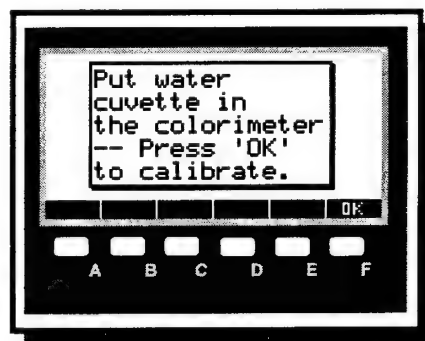


Figure 73. The HP 48 colorimeter calibration program.

To read the absorbance of their standard solutions, students run the MEAS (MEASure) program. This program prompts students to enter the concentration of the standard being read, and then reads the electrical current from the colorimeter's light

sensor. The calculator converts this current reading to absorbance using the distilled water current value saved during calibration. The solution concentration and the absorbance value are saved in a data array in the calculator. When the reading is complete, students can either end the program, or make another reading (Figure 74).

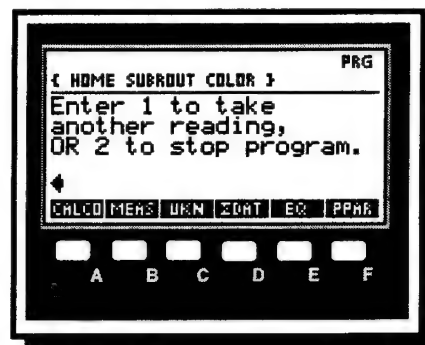


Figure 74. Repeat or quit screen for the HP 48 Program, MEAS.

To find the concentration of the unknown solution, students run a third calculator program, UKN (for UnKnown). This program measures the absorbance of the unknown solution and applies the calibration data to find the unknown's concentration. The slope, intercept, correlation coefficient, and unknown concentration are then displayed on the calculator screen. Sample results of UKN are shown in Figure 75. All three programs are listed in full and explained in Appendix B.

To keep the calculator/colorimeter combination from becoming a "black box," one of the pre-lab exercises gives students sample data and requires them to perform the data analysis themselves. The purpose of this exercise is to understand the calculations that the calculator is automatically performing. This exercise may be performed as a class or in discussion groups to minimize student confusion and frustration.

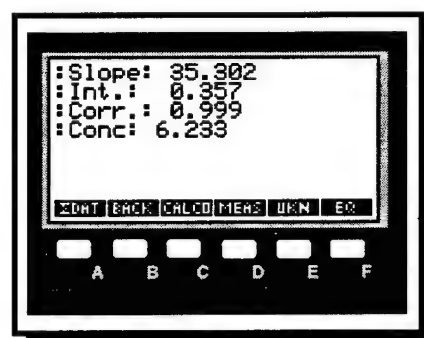


Figure 75. Sample output for the HP 48 program, UKN.

Students recognize the relevance of this experiment when they measure the concentration of chlorine in water taken directly from the laboratory tap. This concentration is easily measurable and in the range of the given standard solution. The experiment design, data acquisition, and application of this experiment all demonstrate the process of science. Students who successfully complete this experiment have experienced the comprehension, application, and analysis levels of Bloom's taxonomy.

Concepts, Technology, and Bloom's Taxonomy

The relationship between the chemistry concepts, technological tools, and taxonomy learning levels in this experiment are shown in Table 11.

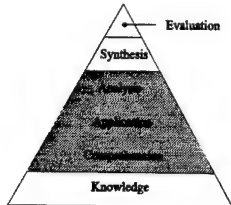
| Chemical Principles | Technology | Learning Level |
|---|----------------------|---|
| Reflection and transmission of color | LabWorks colorimeter | Comprehension Application Analysis  |
| Absorption spectra | | |
| Beer's Law | HP 48 calculator | |
| Preparation of standard solutions | | |
| Calculation of an unknown concentration | | |

Table 11. Chemical principles, technology, and Bloom's taxonomy learning level associated with the experiment, "Colorimetry and Determination of Chlorine Concentration." This experiment requires students think and learn at the comprehension, application, and analysis levels of Bloom's taxonomy.

Using Turbidity to Find Sulfate Concentration

The final experiment in this block of instruction involves a new application of new technology. Turbidity measurements generally have not been performed in introductory laboratories because of the prohibitively high cost of measuring turbidity. Educational turbidimetry is made possible because the LabWorks colorimeter is capable of measuring scattered light as well as transmitted light. (The principles of inexpensive turbidity measurement are covered in Chapter 3 of this thesis.) Students are given a sulfate solution of known concentration from which they make a series of standards. They add a small amount of barium to the standards, and then measure the turbidity of the precipitated barium sulfate.

The LabWorks colorimeter is employed, with light sensors at 90° and 180° from the light source, and with the HP 48 calculator controlling the LabWorks interface. Students participate in experiment design by understanding the significance and difference between scattered and transmitted light with respect to turbidity measurements. After the measurements are made, students decide whether simple nephelometry is sufficient for finding the concentration of the unknown, or if the extra equipment and calculations necessary for ratio nephelometry are required.

Students run two HP 48 programs to measure turbidity. The first program, TURINI (TURbidity INItialization), illuminates the appropriate LEDs in the LabWorks interface and sets both DAC1 and DAC2 to 1 volt in preparation for reading current from the I1 and I2 inputs. This program only needs to be run once.

When the turbidimeter is initialized, students measure each of their solutions using the RDTBD (ReaD TurBiDimeter) program. This program measures the current from both I1 and I2 inputs on the LabWorks interface. The logarithm of the transmitted signal is calculated along with the ratio of scattered signal divided by the



Figure 76. Sample data from the HP 48 program, RDTBD.

logarithm of the transmitted signal. These four values are then displayed by the calculator as shown in Figure 76.

Students must record all four values, along with the associated concentrations, on their data sheets for later analysis. This experiment was originally designed to have students enter the solution concentration and then store all values in a data array, similar to the procedures in "Colorimetry and Determination of Chlorine Concentration." The data array would have to be five columns wide, and use as many rows as there are samples measured. The HP 48 calculator is capable of storing and manipulating large data arrays, but the calculator's small screen makes displaying this data impractical. Calculator storage of the data was abandoned in favor of using other methods, such as a computer spreadsheet, for data analysis.

Data analysis consists of plotting two sets of data: (1) scattered signal versus concentration; and (2) ratio of scattered signal divided by transmitted signal versus concentration. These calibration graphs are then used to find the concentration of the

unknown sulfate solution. The linear nature of the two sets of data and the accuracy of their unknown calculations will help students decide which turbidity measuring method is the best to use. Group data comparisons and discussions are an important part of the learning process in this part of the experiment, which draws students into the evaluation level of learning according to Bloom's taxonomy. This critical thinking exercise is the highest learning point of the entire spectroscopy unit.

Concepts, Technology, and Bloom's Taxonomy

The chemical principles, technology employed, and Bloom taxonomy learning levels accessed by this experiment are summarized in Table 12.

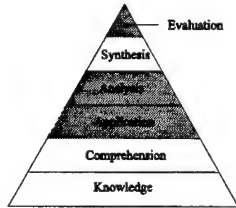
| Chemical Principles | Technology | Learning Level |
|--|---------------------------------|--|
| Using scattered and transmitted light to measure impurity levels | HP 48 | Application Analysis Evaluation  |
| Advantages and limitations of turbidity measuring devices | LabWorks Interface | |
| Preparation of standard solutions | | |
| Determining the concentration of an unknown solution | LabWorks wood block colorimeter | |
| Evaluating ratio nephelometry and simple turbidimetry methods | | |

Table 12. Chemical principles, technology, and Bloom's taxonomy learning level associated with the experiment, "Using Turbidity to Find Sulfate Concentration." This experiment requires students think and learn at the application, analysis, and evaluation levels of Bloom's taxonomy.

Use of Hardware, Software, and Simulation

The optical spectroscopy unit employs many of the hardware and software tools introduced in Chapters 3 through 6. The flow of experiment activities and tools employed for each activity shows that all types of tools are useful for all levels of learning. Simulations can teach knowledge, as well as evaluation, and data acquisition tools can be used for all levels of Bloom's taxonomy. The flow of concepts, simulation, and data acquisition tools is shown in Figure 77.

Experiment Activities




| | | | | |
|--|---|---|---|--|
| Simulation | Identify unknowns using <i>Atomic Spectra</i> |  | Test Bohr's electron orbital theory | |
| Data Acquisition Software/ Hardware | |  | | Colorimetry and turbidity measurements |
| | | |  | |

Figure 77. The flow of experiment activities, and the different tools used for each activity. Students use both simulations and wet chemistry experiments to explore concepts and exercise critical thinking and high-level learning skills.

CHAPTER 10

ENERGY-ENVIRONMENT SIMULATOR

This experiment is a computer simulation that involves no wet chemistry. The experimental procedures are based on a demonstration given to students at the U.S. Air Force Academy using a suitcase-sized analog energy simulator.¹⁰³ The analog simulator was adapted to an MS-DOS computer program that one or two students could use while in the chemistry laboratory. The simulation program is discussed in detail in Chapter 6 of this thesis, and the entire experiment is included in Appendix A.

Statement of Original Work

As explained in Chapter 6, the Energy-Environment Simulator (EES) has been used as a demonstration tool for many years, both in an analog hardware version, and as computer software. Original products of this project include: (1) the application of this tool in a situation where each laboratory group interacts with their own simulator, and (2) relation of the critical thinking skills to higher learning levels in Bloom's taxonomy.

Energy-Environment Simulator Background

Most of the experiment handout is devoted to explaining various parts of the EES display and showing students how to control different parts of the simulator. This exercise should occur in the later part of the course, as it incorporates many different concepts into a single exercise. No background is provided on environmental strategies; students are expected to determine the best course of action for themselves.

Student Experiment Procedures

This simulation deals with nonrenewable resources, population, and pollution. Students use the software to balance energy sources and demands to make nonrenewable resources last as long as possible, while simultaneously trying to develop new technologies. The experimental procedures require students to try different energy simulator configurations and compare their results from one trial to the next. Students are then asked a series of questions about what worked and what did not work with their energy conservation styles.

In the first part of the exercise, students are asked to start the simulation and observe what happens. They are asked to record which nonrenewable resources ran out first, and how many years those resources lasted. Students also record the length of time before the population ran out of food. Next, students adjust the population control to zero population growth and start the simulator again. This exercise demonstrates the effect of

an increasing population on the amount of time necessary for energy and food to be depleted.

Finally, students start making changes to energy production and consumption. They compare the results of their actions with the first trials in which they made no changes. When they start improving their management skills, they reintroduce population growth to see once again the result of a growing population on the usage rate of nonrenewable resources.

Cooperative learning can also be part of this exercise. Students are encouraged to talk among themselves and share their experiences and methods. These actions form the heart of the evaluation level of Bloom's taxonomy. When students can determine *by themselves* the proper courses of action, they have demonstrated the highest level of critical thinking and learning skills.

As with many simulation programs, different strategies can be used to achieve the final goal of energy self-sufficiency. The purpose of this experiment is not to provide answers, but to pose questions and get students to consider and discuss the simulated problem. This experiment is an invaluable tool for linking concepts previously learned, as well as encouraging students to devise solutions to future problems.

Chemistry Concepts and Pollution

The last questions students answer in this exercise refer to specific chemistry questions dealing with the different types of pollution in the EES: air pollution, heat pollution, and nuclear waste. These questions follow:

- Why does increasing coal usage cause the air quality to worsen? Write two chemical reactions involving coal (or impurities found in coal) that show the formation of air pollutants.
- Why is unused heat a form of pollution? List and explain two harmful effects on a natural lake if its temperature were suddenly raised 10°C.
- One of the most harmful by-products of nuclear fission is an isotope of strontium, ^{90}Sr . Why is this isotope particularly deadly to humans? (Hint: Consider the periodic table and another element that reacts in a similar manner to strontium.)

Concepts, Technology, and Bloom's Taxonomy

The concepts addressed, the technology employed, and the Bloom's taxonomy learning levels accessed by students in this experiment are outlined in Table 13.

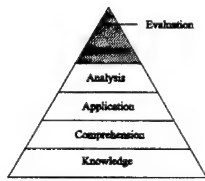
| Chemical Principles | Technology | Learning Level |
|---------------------------|------------------------------|--|
| Energy conservation | Energy-Environment Simulator | Synthesis Evaluation  |
| Exponential growth | | |
| Cause-and-effect analysis | | |

Table 13. Chemical principles, technology, and Bloom's taxonomy learning level associated with the experiment, "Energy-Environment Simulator." This experiment requires students think and learn at the synthesis and evaluation levels of Bloom's taxonomy.

CHAPTER 11

INSTRUCTOR SUPPORT AND TRAINING

In order for students to benefit from the educational ideas and technological tools developed in this project, professors and teaching assistants must support these ideas. Philosophical inertia and other factors may hinder changes in teaching styles and use of advanced laboratory tools. Once these barriers are breached, however, students can benefit by learning chemistry concepts, sharpening their critical thinking skills, and perhaps even enjoying the process.

Statement of Original Work

The one-day and one-week workshops discussed in this chapter were implemented prior to this project's inception. The use of these workshops to specifically encourage paradigm shifting and to introduce higher learning levels is an original idea of the author and the Amend research group.

The Need for Faculty and TA Support

Any educational strategy—not just the strategy developed here—needs the full backing of all participants in the education process. For example, if a professor does not

see the merit of using Bloom's taxonomy and technology, those tools will not be included in the course he or she develops.

A more subtle resistance to higher-level learning occurs when the professor implements the technology-based learning model, but the laboratory teaching assistants do not understand the model or its associated teaching tools. Comments from the teaching assistant such as, "This experiment doesn't produce good results," or "The computers don't work," will immediately disengage students from the process of science and the upper learning levels of Bloom's taxonomy. This undermining is often not a purposeful act to inhibit learning. It may be a result of the instructor's discomfort with technology or a resistance to learning new experiments and methods.

Paradigm Shifting

The way an instructor views teaching and appropriate teaching methods is called a paradigm. Paradigms are ways of viewing the world around us that help filter out unwanted or extraneous information, allowing daily tasks to be accomplished more readily. Unfortunately, paradigms can often remove good information along with the bad. This process has been termed the "paradigm effect."¹⁰⁴ To avoid the pitfalls of the paradigm effect, instructors need to step outside traditional teaching paradigms and take an unbiased look at new teaching models and tools. Looking at new ideas from a new perspective results in a paradigm shift.¹⁰⁵

A paradigm shift is necessary because new technology employed in an old teaching method will produce poor results. As stated in the introduction to this project,

technology by itself will not improve education. New technology must be applied using an appropriate teaching model, and the new teaching model must be accepted before it can be implemented.

Making the Model Work

Professors who want to implement a new teaching model must instigate a paradigm shift in the instructors who will be using the new method. The success of paradigm shifting depends on the personalities of the presenter and of the target audience, and no formula can guarantee success. However, the following actions can help bring about the necessary paradigm shift:

- Communicate instructor expectations.
- Know the tools.
- Introduce technology gradually.
- Communicate student expectations.
- Experience success

The first and most important step toward making the new educational model successful is to communicate the professor's expectations to the instructor cadre. The teaching assistants must understand the strengths and weaknesses of the model and how it meets the course goals. A course overview, followed by a faculty discussion session, is one method of sharing this information.

Next, the instructors must have a thorough knowledge of the tools necessary to implement the model. Instructors who can troubleshoot technical problems will be able to keep students focused on chemistry and learning, rather than on getting equipment to function properly. In-house training sessions can provide instructors with the experience

necessary to master the hardware and software tools. During training, instructors perform experiments that are part of the semester curriculum, encounter pitfalls that students will face, and solve problems that occur during the laboratory periods.

The chances of successfully implementing a new learning model also increase if the technology is slowly introduced to students and faculty. Paradigm shifting is a fairly slow process, and a gradual change is more likely to be accepted than a total immersion in new technology. The laboratory curriculum should start with a traditional experiment, or one that uses technology only sparingly. Once students become more confident using technology, they can work with complicated experiment procedures and experiment design projects. If students are expected to do too much too soon, they may develop an aversion to using technology that will be very difficult to overcome.

To benefit from this learning model and its required technology, students must understand what will be expected of them in the laboratory. Just as the instructors have their roles in the learning model, students must also know their roles. Students who are used to passive learning situations may find the thought-intensive, active-learning exercises unsettling. In these cases, the student paradigm needs to shift. Once students appreciate the benefits of active learning, they will be able to help themselves and each other while learning in the active environment.

Finally, instructors need to experience for themselves that the model works and can promote higher-level learning. This cognizance cannot come from reading about or watching the technology being used, but only from a hands-on self-demonstration of the technology at work.

Introducing the Learning Model and Tools to Teachers

College and university instructors around the country have attended workshops dedicated to implementing active learning models that incorporate technology. Two types of workshops are offered to introduce instructors to the most effective academic uses of technology. The first type of workshop takes place in a single day and is held at different schools throughout the country. The other type is a one-week long summer workshop held at Montana State University.

One-Day Workshops

The one-day workshops consist of a morning seminar, followed by a question-and-answer session. The afternoon portion is a hands-on exercise that provides participants with the opportunity to operate the new laboratory technology. Sample experiments are provided, or participants can perform experiments from their own curricula. The one-day workshops provide an introduction and overview to technology-assisted learning, but the week-long workshops provide a more complete picture of the learning model's benefits.

One-Week Workshops

The one-week workshops cover almost the same material as the single-day workshops, but in greater detail. The seminar portion is expanded to include specific experimental techniques and teaching strategies that incorporate new technology. Participants are given two days to work on individual projects that demonstrate the

capabilities of properly used technology. After one week of intensive exposure to new technology, participants return to their respective schools ready to apply the techniques they have learned.

Summary of Workshop Participation

The author served as an instructor and presenter at the week-long workshops held at Montana State University in the summers of 1995, 1996, and 1997. Each summer, two week-long workshops took place, making a total of six workshops. In addition, the following one-day workshop presentations were offered to college faculty as part of this project:

- November 1996—Oregon State University, Corvallis, OR
- November 1996—Pierce College, Seattle, WA
- February 1997—Blinn College, Brenham, TX
- March 1997—Tulsa Community College, Tulsa, OK
- April 1997—SUNY, Albany, NY
- June 1997—Carroll College, Waukeesha, WI
- July 1997—Hamline University, St. Paul, MN

Conclusions

In addition to developing a learning model and the technological tools to implement this model, information dissemination has been a significant part of this project. The model will be more effective if instructors and students understand its concepts, tools, and benefits. As with any educational project of this scope, effective communication is the key to success.

CHAPTER 12

EVALUATION AND CONCLUSIONS

Evaluating the effectiveness of the tools and learning exercises proposed by this thesis is a challenging proposition. Milton Glick wrote, "Increased productivity in higher education is hard to define, let alone quantify or measure."¹⁰⁶ The challenge lies in determining the degree to which students are learning at the higher levels identified by Bloom's taxonomy. While students are engaging in higher-level learning activities, the testing methods only target knowledge and comprehension learning levels. This deficiency is illustrated in Figure 78.

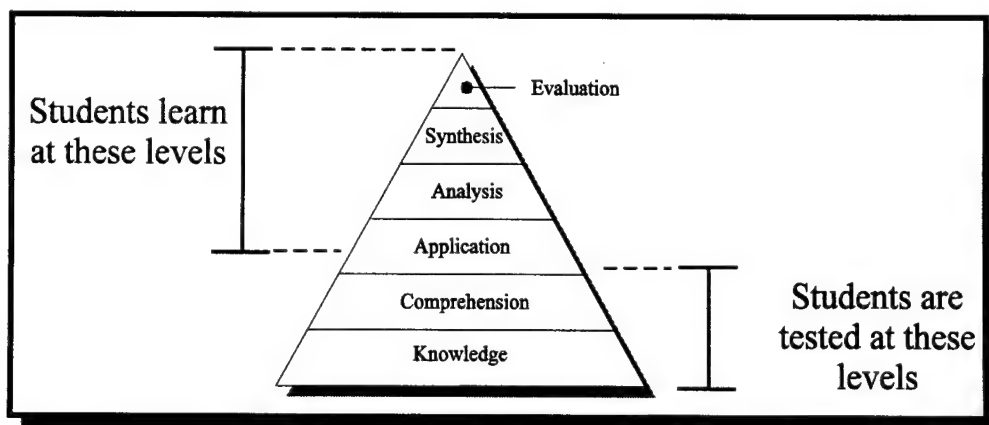


Figure 78. The problem with using standard assessment tools to evaluate the effectiveness of high-level learning exercises. While we encourage students to develop higher-level learning processes, traditional evaluation methods focus on lower-level learning.

Despite these difficulties, attempts have been made to assess this learning model and its component tools. Throughout the fall 1996 and spring 1997 semesters, students in Chemistry 121 classes performed discovery-based experiments, and then were given surveys that tried to determine how much they learned and how much they thought they learned. Many students also wrote comments about what they liked and did not like about the experiments. The results of these surveys are compiled in this chapter.

Statement of Original Work

All evaluations presented in this chapter except the Chemistry 131 project survey question are original works and ideas of the author.

Learning from Discovery-based Experiments

In the spring of 1997, an opportunity to directly compare a discovery-based experiment with a traditional experiment occurred. One experiment in the chemistry 121 curriculum explored colorimetry and determination of nitrate ion concentration. The procedures for this experiment were rewritten into a discovery-based format, and this new experiment was given to approximately half of the students. The other half performed the original experiment as it was written in the laboratory manual. One hundred and sixty-five students participated in this study. Eighty-three students performed the discovery-based version of the experiment, while 82 followed the traditional experiment. Procedure outlines of the original experiment and the discovery-based version of the experiment are printed in Appendix C.

One week after the experiments, a quiz was administered to determine the degree to which students learned the experiment concepts. All students received the same questions, which were written by Kari Cargill, an experienced teaching assistant who was not involved in this project.

Colorimetry Quiz and Results

The students answered the following questions to determine their relative learning. The results for all questions are shown in Figure 79.

1. **What is true of a red-colored solution?**
 - a. **This solution absorbs red light.**
 - b. **This solution absorbs all colors except red.**
 - c. **This solution transmits only green light.**
 - d. **This solution transmits all colors except red.**

The correct answer to this question is (b) **This solution absorbs all colors except red**. Sixty-five percent of the discovery-based students answered this question correctly, while 63 percent of the traditional experiment students gave the correct answer.

2. **On the back of this sheet, explain your answer to Question #1.**

Because this was a short-answer question, correct answers had to point out that red light transmitted through the solution, while other colors of the visible spectrum are absorbed. Twenty-seven percent of the discovery-based students answered this question correctly, while 24 percent of the traditional experiment students gave the correct answer. The scores for this question were much lower than for question #1. This difference in scores occurred because those students who missed question #1 were very unlikely to get question #2 correct.

3. In order to make up a sample of blue food coloring with a final concentration of 8 parts per 10 mL, you would:
- a. add 2 mL food coloring to 10 mL water.
 - b. add 2 mL food coloring to 8 mL water.
 - c. add 8 mL food coloring to 10 mL water.
 - d. add 8 mL food coloring to 2 mL water.

The correct answer to this problem is (d) add 8 mL of food coloring to 2 mL of water. Sixty-six percent of the discovery-based students answered this question correctly, while 72 percent of the traditional experiment students gave the correct answer. The purpose of question #3 was to assess how well students understood and retained procedural concepts.

4. A source of nitrates found in our world includes:
- a. fertilizer
 - b. sewage
 - c. processed meats
 - d. all of these
 - e. none of these

The correct answer to this question is (d) all of these. Eighty-nine percent of the discovery-based students answered this question correctly, while 74 percent of the traditional experiment students gave the correct answer. This application-based question shows the only statistically significant difference between the traditional and discovery-based students.

5. Using the graph below, estimate the concentration of a sample having absorbance of 1.00.
- a. 0.00 mg/L
 - b. 0.10 mg/L
 - c. 0.25 mg/L
 - d. 0.40 mg/L

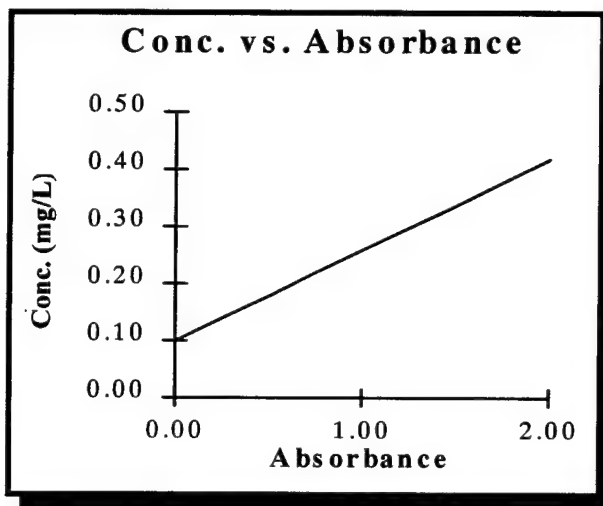


Figure 79. Concentration versus absorbance plot for question #5.

The correct answer to this question is **(b) 0.10 mg/L**, and all students did very well on this question. Ninety-five percent of both traditional and discovery-based students answered this question correctly. The results for all questions are shown in Figure 80.

Evaluation of Long-term Retention

Two months after the colorimetry experiment was performed, students were given the same quiz to see if traditional or discovery-based methods affected long-term concept retention. Again, with the exception of question #4, the results of both types of experiments are statistically similar. The results are summarized in Figure 81.

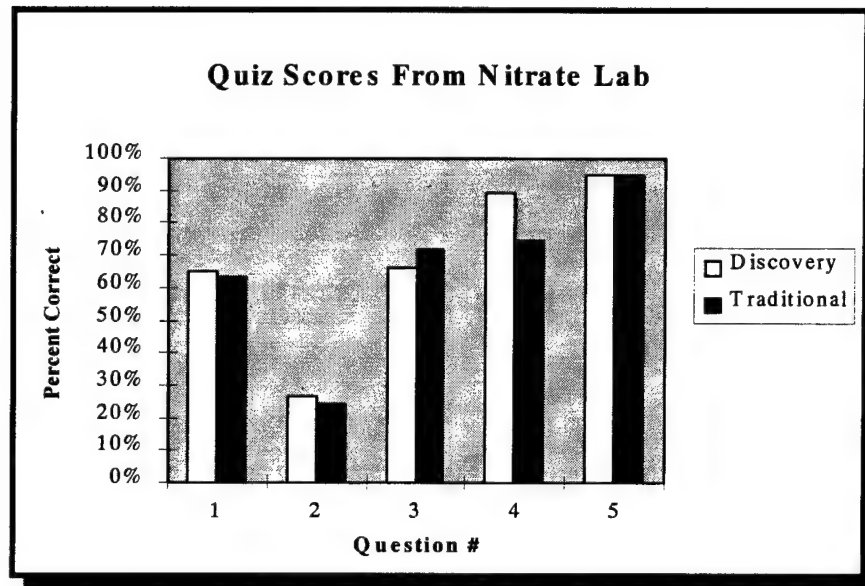


Figure 80. Relative performance of students learning with traditional and with discovery-based experiments. Other than question #4, there is no significant difference in learning at lower levels of Bloom's taxonomy.

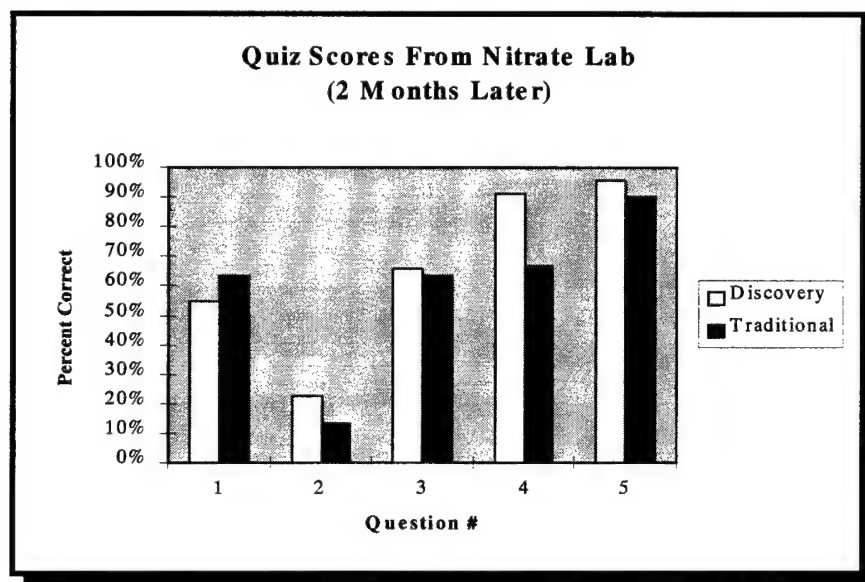


Figure 81. Long-term retention of colorimetry concepts. Like the first quiz, the two types of experiments teach basic concepts equally, with the possible exception of question #4.

Problems With This Type of Evaluation

Comparing the effectiveness of discovery-based experiments to traditional experiments is full of problems and pitfalls. Problems include evaluation methods, instructor experience level, and student sample size. Despite these problems and the need to develop new metrics, useful information can be gained from these evaluations.

The first and most significant problem with this sort of evaluation is that the multiple-choice and short-answer questions only test learning at the knowledge and comprehension levels. The greatest benefit of discovery-based experiments is that they enable students to learn at the analysis and synthesis levels of Bloom's taxonomy. Multiple choice questions cannot ascertain whether or not a student has mastered a concept at the analysis or synthesis level.

Many other factors contribute to uncertainty when drawing conclusions based on this data. Previous student experience and academic ability were not factored into these evaluations. Likewise, no allowance was made for laboratory teaching assistant experience. Also, the relatively small number of quizzes returned gives more weight to outlying data points.

Laboratory experiments that allow students to experience higher levels of learning should be pursued, even though it is difficult to evaluate whether learning at higher levels has been achieved. We can reason that discovery-based experiments teach at lower levels of Bloom's taxonomy equal to (or possibly better than) existing traditional experiments.

When evaluation methods are developed that can effectively test higher levels of learning, then the true value of discovery-based experiments will be known.

Student Perceptions of Discovery-based Experiments

Also in the spring 1997 semester, students in MSU's Chemistry 121 laboratory sections performed a prototype discovery-based lab titled, "Exploring the Chemistry of Gases in Solution." This experiment, developed as part of this project, is discussed in Chapter 8 and is printed in its entirety in Appendix A.

The week after students performed the experiment, they were given a survey to determine how well they enjoyed the discovery-based experiment and their perceptions of how well they learned chemistry concepts using this style of teaching. The survey consisted of five multiple choice questions, with space provided for student comments. One hundred and seven students returned their surveys. The questions and student responses follow.

The first survey question addressed how well students liked the "Chemistry of Gases in Solution" experiment itself, compared to other experiments in the curriculum. Actual statements and student responses are summarized in Figure 82.

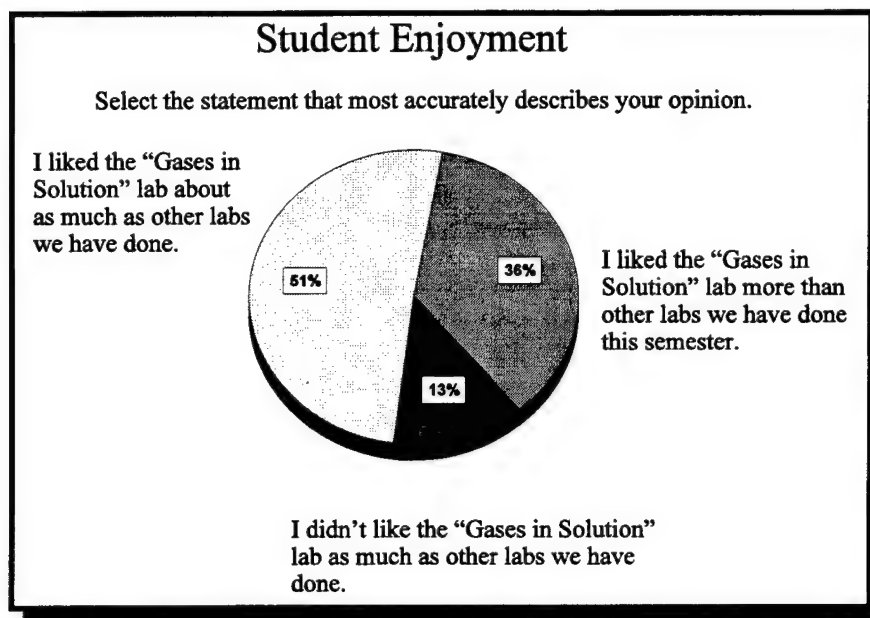


Figure 82. Student enjoyment of prototype discovery-based experiment. The discovery-based experiment was generally more popular than traditional experiments.

Eighty-seven percent of the students surveyed enjoyed the discovery-based experiment as much or more than the traditional experiments that comprised the rest of the course.

The next survey question asked how well students thought they learned from the new experiment experiment, compared to other experiments performed that semester.

The statements and results are summarized in Figure 83.

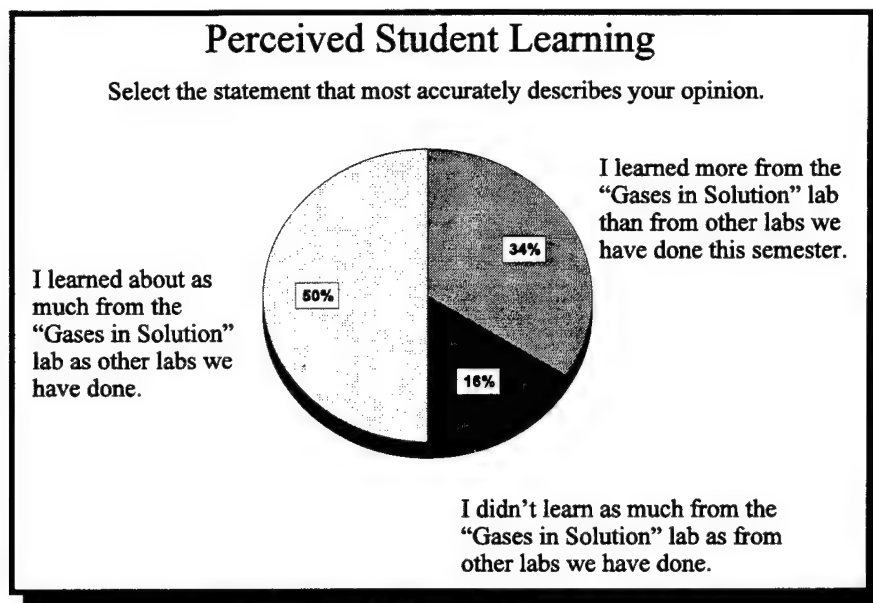


Figure 83. Perceived student learning from prototype discovery-based experiment. Students believed they learned more from the discovery-based experiment than from traditional experiments.

Eighty-four percent of the students believed they learned as much or more from the discovery-based experiment as from traditional experiments.

The third question asked students if they thought "Exploring the Chemistry Gases in Solution" should be used again or removed from the course. The responses to this question are summarized in Figure 84.

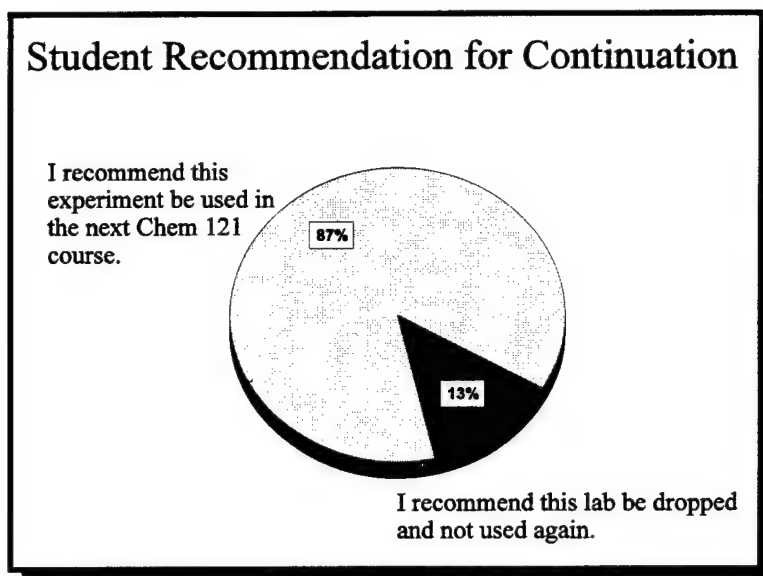


Figure 84. Student recommendations to either keep or remove this experiment from future Chemistry 121 courses. Students recommended that the discovery-based experiment be used again.

Eighty-seven percent of the surveyed students thought the experiment should be kept for future courses.

The fourth survey question asked which type of learning students enjoyed, traditional or discovery-based. The results are summarized in Figure 85. Thirty-nine percent of the students surveyed acknowledged that they enjoyed learning more through the discovery-based process. Fourteen percent admitted that they enjoyed learning in a more traditional manner. Forty-seven percent of the students did not favor one style of learning over the other. The large percentage of undecided responses may indicate that students might not have fully understood the question.

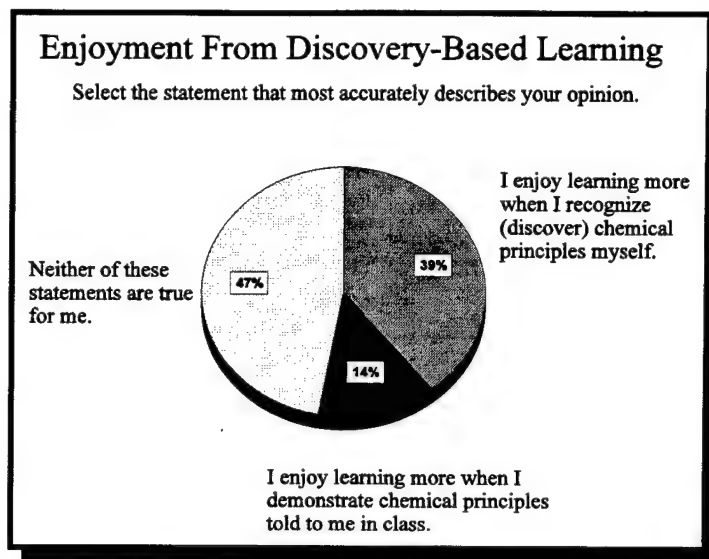


Figure 85. Perceived student enjoyment from traditional versus discovery-based learning. A large percentage of students enjoy learning by the discovery-based process.

The last question on the survey produced some interesting and unexpected results. Students were asked to rate the amount they learned from both traditional and discovery-based methods. The results from this question are summarized in Figure 86.

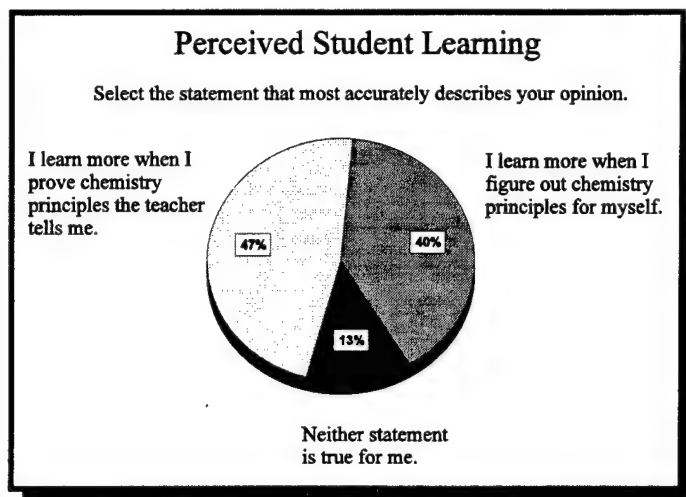


Figure 86. Perceived student learning from traditional versus discovery-based learning. Most students felt they learned more using traditional methods.

At first inspection of the responses to this question, it appears as though students believe they learn more by proving information they receive in lecture than by uncovering the information themselves. The results of this question also seem to contradict the responses to the first four questions. The shortfalls that appear from student responses are not in the learning model or technological tools, but in the evaluation itself. This survey was given at a time in the semester when chemistry concepts appeared in the laboratory experiments before they were covered in lecture. Many students felt that they were not given sufficient background information to successfully complete the experiments, resulting in a large amount of frustration. Students most likely interpreted question #5 incorrectly and thus provided misleading responses. Student responses to this question demonstrate that they need sufficient

background (knowledge and comprehension levels of learning in Bloom's taxonomy) to be able to learn from either traditional or discovery-based experiments.

Chemistry 131 Projects

Student-designed experiments and discovery-based learning have been employed as effective learning tools, and the responses to the final question may have been an anomaly. The chemistry 131 projects discussed in the introduction produced a more strongly positive student response.¹⁰⁷ Figure 87 shows the results of students surveyed about Chemistry 131 projects:

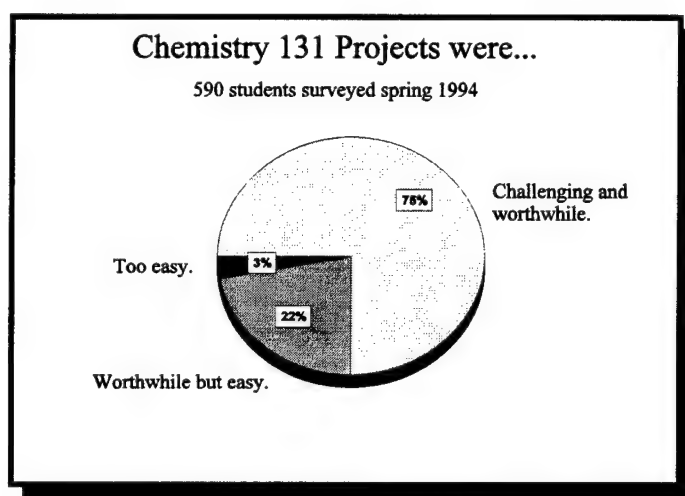


Figure 87. Student survey about Chemistry 131 projects. An overwhelming majority of the students felt this exercise was worthwhile.

Student Comments

Both in surveys and in laboratory reports, students have made comments concerning upper-level learning through discovery-based experiments. These comments

reflect both positive and negative feelings about using these learning tools. Following are selected unedited comments:

- I liked the different application areas. It helped me to apply these experiments to real life situations. I'm not too sure it gets me more involved with the experiment, but it does make what we're doing more practical to me.
- I liked the experiment because once again it gave us a question to answer which always makes the lab go better.
- I did like the different application areas. I feel it gave us a reason to run the experiment other than just because the lab manual said to.
- I feel this was by far the best lab we have done. The concepts were much more hands on rather than reading from a text book about how to do things, we actually got to decide.
- I did like the different application areas, but I did not like the lab in general because I didn't understand what was going on from point one. I just had a hard time understanding it. I think I would rather have done the regular experiment.
- Continue to use the discovery-based method of teaching. I got a lot more out this class than some of my friends in other sections.

Project Conclusions

The goal of this project was to develop a teaching model and technological tools to engage students in a different, more rewarding, and effective type of learning. The report to the National Science Foundation, *Shaping the Future*, listed many goals that educational institutions should achieve through curriculum reform. One of these goals is to "build into every course inquiry, the process of science (or mathematics or engineering), a knowledge of what SME&T practitioners do, and the excitement of cutting-edge research."¹⁰⁸ Bloom's *Taxonomy of Educational Objectives* was used to

quantify these new levels of learning. The learning model, hardware tools, and software tools were integrated into a set of laboratory experiments. Experiments were designed so that students must work at the taxonomy's higher learning levels to successfully complete them, thus demonstrating mastery of the required skills.

Along with developing the model and the tools, an attempt was made through workshops to alter the outlooks of teachers and students to facilitate the success of this learning strategy. Ultimately, new instructor and student attitudes are necessary to make the new tools work effectively.

In addition to presenting new technology (i.e., the hardware, software, and experiments), this project introduces viable methods that can be used to design and produce essential tools and applications that move students to higher levels of learning. Educators can modify the development model provided in this project to meet their unique pedagogical needs. Researchers can build their own sensors and create curriculum-specific software to make data acquisition simpler and more powerful. Devices other than HP calculators can be adapted to control the LabWorks interface. Future experiments can be written or adapted using this project's experiments as templates.

Many valuable learning tools can be developed using this project as a model. If properly implemented, these educational tools will increase student learning and enhance their overall college experience.

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APPENDICES

APPENDIX A

EXPERIMENT LISTING

EXPLORING THE CHEMISTRY OF GASES IN SOLUTION

LEARNING OBJECTIVES

The objectives of this experiment are to:

1. understand how temperature affects the solubility of gas in a liquid;
2. be familiar with acid/base properties of water and the concept of pH;
3. understand what a buffer is and how it works; and
4. know how dissolved CO_2 affects the pH of different solutions.

BACKGROUND

In this experiment you will take some seemingly random bits of chemistry knowledge and bring them together to solve one of the application problems given at the end of this experiment. This is how research is performed. Scientists are presented with a problem and a small amount of background data. Then they make measurements in the laboratory and come to a conclusion about how to solve the problem. This section contains short explanations of the following topics:

- K_w and Autoionization of Water
- Buffers
- Solubility of Gases in Water
- Reaction of CO_2 in Water

It will be up to you and your lab partner to use this information to answer the laboratory questions and solve one of the application problems presented at the end of this experiment.

Acids, Bases, and pH

There are different theories concerning acids and bases. This section describes the definition proposed by Svante Arrhenius. According to Arrhenius' theory, acids are chemicals that break apart in water into positive and negative ions, with the positive ions being H^+ . (H^+ is also written as H_3O^+ .) The H^+ is called a proton, while the H_3O^+ form is called a hydronium ion. Acids are then called proton donors, because they increase the number of H^+ ions in a solution. Bases, on the other hand, are defined as proton acceptors, because when they dissolve in water, the H^+ ion concentration decreases.

Many chemical reactions, including chemical reactions in our bodies, are very sensitive to H^+ ion concentration. The H^+ ion concentrations with which scientists normally work are very small and can change by many orders of magnitude. Typical concentrations range from 10^{-1} moles of H^+ per liter of solution for very concentrated acids, to 10^{-14} moles per liter for concentrated bases. To make these numbers easier to handle, acids are commonly described using the pH scale. pH is defined as the negative of the logarithm of hydronium ion concentration expressed in moles per liter, or:

$$pH = -\log[H^+] \quad (1)$$

Using pH units, the range of 10^{-1} to 10^{-14} becomes 1 to 14, which is much easier to work with. Using the pH scale, acidic solutions have pH values less than 7, while bases have pH values greater than 7. A neutral solution (neither acid nor base) has a pH of 7.

Square bracket [] notation means *concentration in units of moles per liter*, or molarity (M).

K_w and Autoionization of Water

Water is the cornerstone of common acid/base chemistry. Almost all of the acid/base chemical reactions found in your textbook take place in a water solution. Consider water itself: Is this compound an acid or a base? Does water donate H^+ ions, or accept them? The answer is, it does both! At 25°C , a small amount of water automatically breaks up into H^+ and OH^- ions.



This process is known as the *autoionization* or *autoprotolysis* of water. For pure water, the concentrations of H^+ and OH^- ions are equal to 1.0×10^{-7} moles per liter. The product of $[H^+]$ and $[OH^-]$ is then 1.0×10^{-14} . This value, 1.0×10^{-14} , is called the autoionization constant of water at 25°C , and is denoted by K_w . K_w is important because

as $[H^+]$ goes up (due to addition of an acid to a solution) $[OH^-]$ goes down. The product $[H^+] \times [OH^-]$ is always the same.

Buffers

A buffer is a chemical that, when added to a solution, tends to keep the pH constant. Buffers have the ability to donate and accept H^+ ions, keeping an established balance between $[H^+]$ and $[OH^-]$. Different buffers maintain different pH values. Buffers also have a specific *buffer capacity*, which is the amount of acid or base you can add to a buffered solution without significantly changing the pH. If you add enough acid or base to overcome the buffer capacity, the pH of the solution will change. Buffers are very important, biologically. For example, human blood is buffered to be pH 7.40. If the pH goes lower than 7.35 or higher than 7.45, the hemoglobin won't carry oxygen properly.

Solubility of Gases in Water

It is easy to understand how a solid can dissolve in water, or how you can mix two different liquids together into a single solution. It's not obvious, however, that you can dissolve a gas

A solid, liquid, or gas dissolved in water is said to be *in solution*.

in a liquid. After opening a can of soda pop, bubbles form that are carbon dioxide escaping from the liquid. The increased pressure in the sealed can keeps the CO_2 in solution until the pressure is released by opening the can. The dissolved CO_2 is also why these soft drinks are called *carbonated*.

The temperature of water also affects the amount of gases that dissolve in it. Warm soda goes flat faster than cold soda. As you heat a pan of water (to make spaghetti, for example), you see bubbles form in the water long before the water starts boiling. Those bubbles are formed by air that comes out of solution while the water heats up. The conclusion you draw from these observations is that **as temperature increases, gas solubility decreases**.

Reaction of CO_2 in Water

When carbon dioxide molecules dissolve in water, they do more than just sit between water molecules. A small amount of CO_2 reacts with water to form a carbonic acid. This reaction is:



SAFETY PRECAUTIONS

Observe all normal safety precautions for this experiment. Be careful working with hot plates. Even though the experiment works mostly with water and soda pop, these solutions will be heated to high temperatures. Wear safety goggles at all times.

MATERIALS

Reagents:

- tap water, deionized water, carbonated water, lemon-lime soda, cola
- pH 7 buffer (for calibrating pH probes)

Equipment:

- LabWorks interface, HP 48 calculator, connecting cable
- hot plate, pH probe
- buret, thermistor

EXPERIMENTAL PROCEDURES

1. Connect the HP 48 calculator to the LabWorks interface using the four-pin-to-nine-pin serial connector. The nine-pin serial connection is located at the back of the LabWorks interface. Attach a pH probe to the interface using the pH/mV1 connector as shown in Figure 88.

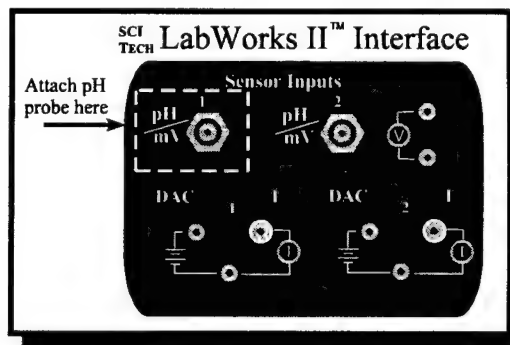


Figure 88. pH 1 connection on LabWorks interface.

2. Obtain about 20 mL of pH 7 buffer solution in a 50-mL beaker. You need enough buffer solution to cover the end of the pH probe. Do not take more buffer than you need.
3. Activate the pH calibration program by pressing the button on the HP 48 calculator located below the PHCAL program. If your calculator display looks like Figure 89, press the B (\square_B) key.
4. The screen that appears in the calculator window should look like Figure 90. Place the pH probe in the buffer solution, and then press the F (\square_F) key, located below the OK prompt.
5. The pH probe will measure for approximately five seconds, then the calculator screen will prompt you to enter the pH of the buffer solution. Enter the pH value of the buffer, then press the \square_{ENTER} key.
6. Use the RDPH program to measure the pH of the following liquids:

| | |
|------------------|-----------------|
| tap water | lemon-lime soda |
| deionized water | cola |
| carbonated water | |

Record the pH values in your data sheet in the "pH before heating" column. The RDPH program will continuously display pH until you press a key on the HP 48 keypad.

7. Look at the ingredients on the carbonated water, lemon-lime soda, and cola. On your Data Sheet, list the ingredients that cause the pH to be less than 7.0.
8. Pour 25 mL of carbonated water in a 50-mL beaker, and heat on a hot plate until it starts to boil. The solution will give off gas bubbles long before boiling. What is the gas being given off?

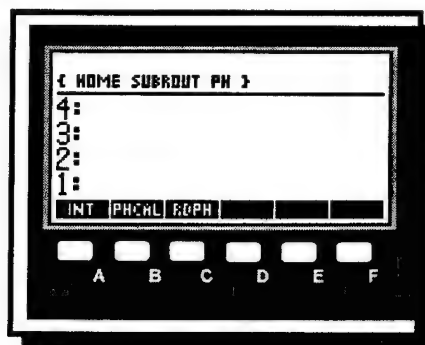


Figure 89. How to access HP 48 programs.

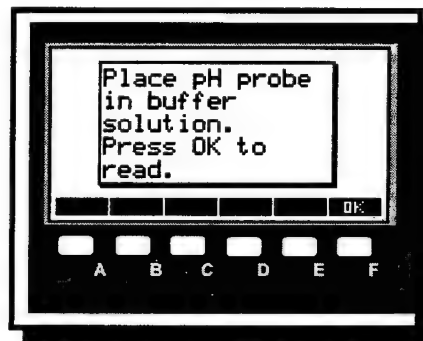


Figure 90. pH probe calibration instructions.

9. Turn off the hot plate and let the beaker cool to room temperature. Measure the pH at room temperature, and record this value in your data sheet in the column labeled "pH after cooling."
10. Repeat steps 8 and 9 for both cola and lemon lime soda. Note: You do not have to heat the tap water and deionized water.

Lab Report Checklist

In addition to the normal written sections (Purpose, Procedure, Data/Calculations, and Conclusions), be sure to include the following in your lab report:

- ☐ Answers to the following questions:
 - Which of the solutions in step 1 had a pH less than 7.0? What caused these solutions to be acidic?
 - What gas did the solutions give off as they were heated?
 - How did the pH of each solutions change after you heated them?
 - What is the relationship between dissolved CO_2 and pH for carbonated water? For cola? For lemon-lime soda?
- ☐ Answers to the questions for one of the applications (You may need to get information from another source, such as the Internet or library):

Biomedical: Blood Gases

Scuba divers sometimes suffer from an affliction known as the bends. What causes this painful and sometimes fatal condition? Discuss how the bends could be prevented, as well as some possible treatments.

Agriculture: Dissolved Gases in Rainwater

How is rainwater different than irrigation water for watering crops? In other words, is one source of water better than the other for the health of the plants? Describe a case in which rainwater is better than irrigation water, and a case where rainwater is worse. What gases can dissolve in a raindrop as it falls through the atmosphere?

Environmental Science: Heat Pollution

A nuclear power plant brings cold water in from a stream to help cool its reactor. The water returned to the stream is *completely* free of radioactivity, but it is 10°C warmer. Is this a form of pollution? If you answered “yes,” what are possible harmful effects?

Name _____

TA _____

Exploring the Chemistry of Gases in Solution
Pre-Lab Questions

1. What causes the pH of tap water to be less than 7.0?

2. How does temperature affect the autoionization of water? (Hint: think about what temperature means in terms of the motion of molecules.)

3. Write a balanced chemical equation that is equivalent to equation (2), but has H_3O^+ as one of the products.

4. The active ingredient in aspirin is acetylsalicylic acid. Why would aspirin cause some people to have an upset stomach? What do you suppose is in the commercial product Bufferin that helps prevent upset stomachs?

5. Carbonic acid is a weak acid. Write a balanced equation that shows carbonic acid donating one proton to water.

Name _____

TA _____

EXPLORING THE CHEMICAL PROPERTIES OF GASES IN SOLUTION
Data Sheet

The pH of Common Solutions and Gas Solubility

| Substance | pH before heating | pH after heating |
|------------------|-------------------|------------------|
| Tap water | | |
| Deionized water | | |
| Carbonated water | | |
| Lemon-lime soda | | |
| Cola | | |

| Substance | pH-lowering Ingredients |
|------------------|-------------------------|
| Carbonated water | |
| Lemon-lime soda | |
| Cola | |

SPECTROSCOPY— EXPERIMENTS USING VISIBLE LIGHT

LEARNING OBJECTIVES

The objectives of this experiment are to:

1. determine the relationship between the colors of the visible spectrum and their corresponding wavelengths and frequencies;
2. identify band and line spectra, and relate the physical state of a light-emitting substance to the type of spectrum observed;
3. determine the relationship between the energy, frequency, and wavelength of light waves;
4. experimentally determine Planck's constant;
5. use the Spectra computer program to identify unknown elements using their emission spectra; and
6. explore Bohr's planetary electron model using the atomic spectrum of hydrogen.

BACKGROUND

For scientists, light is a very important analytical tool. Using light, scientists can determine a large amount of information about unknown substances. The identity of a sample and the amount of sample present are only two examples.

In this experiment we will explore the wave-like nature of light, and show how light's energy is related to wavelength and frequency. Then we will see how light interacts with matter, and how electrons are the key to that interaction. Finally, we will examine how Niels Bohr used light to deduce that electrons moved around atomic nuclei in circular orbits.

Light—Wave or Particle?

In the late 1800s and early 1900s, scientific opinion was divided on whether light was made of waves or particles. In 1873, James Maxwell proposed that light was made up of

magnetic and electric fields that oscillated perpendicular to each other. Thirty years later, Albert Einstein explained the photoelectric effect in such a way that suggested light was made of particles called photons. The truth is that light behaves either as a wave *or* a particle, depending on how it is observed.

Light as a Wave

One of the more convincing bits of evidence supporting the wave model for light is the star pattern observed when a light is viewed through a close-mesh screen (Figure 91). The pattern of alternating light and dark bands radiating from each light source is called an “interference pattern,” and the spacing of the bands is related to the wavelength of the light. This commonly observed phenomenon may be explained by assuming that light has some properties normally attributed to waves, whether they are water waves, sound waves, or waves on a jump rope.

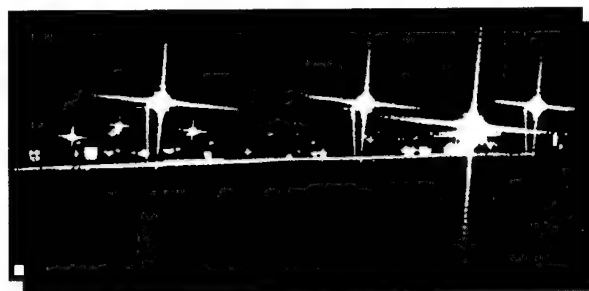


Figure 91. The wave nature of light is illustrated by the interference patterns formed when light passes through a window screen.

Interference is an important characteristic of waves. All forms of wave motion interfere. As waves cross, the individual disturbances add algebraically. If two positively displaced waves cross, a larger wave results. If same-sized positively and negatively displaced waves cross, they will cancel, resulting in no displacement at all.

Figure 92 shows two waves made from shaking a rope. Both waves are displacing the rope upward and they are approaching one other. At the instant the waves cross, they combine to form a single large wave. This addition is known as *positive* wave reinforcement, or constructive interference. Beyond the crossing point, both waves continue on their original paths at their original sizes.

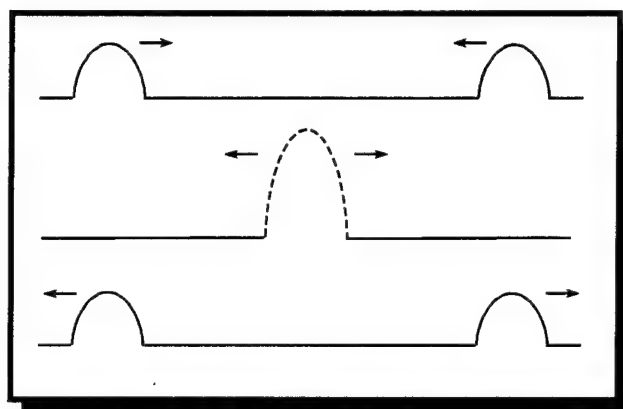


Figure 92. Constructive wave interference.

In Figure 93, two waves of opposite displacement approach each other. If the two waves are the same size, they will cancel each other at the crossing point. When this occurs, the waves *negatively* reinforce each other, and the process is called destructive interference. The term destructive interference is misleading, because the waves cancel each other only at the crossing point. After the waves cross, they continue on their original paths at the same sizes as when they started.

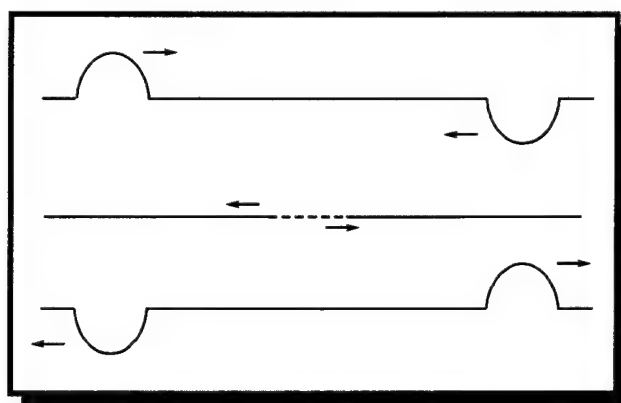


Figure 93. Destructive wave interference.

Wavelength, Frequency, and the Speed of Light

Three symbols— λ , ν , and c —are an important part of any discussion of light waves:

- λ (lambda) represents the wavelength of light. Wavelengths of visible light are usually expressed in units of nanometers. A nanometer is one billionth of a meter or 1×10^{-9} m.

- ν (nu) is the frequency of a light wave, expressed in cycles per second, or Hertz (Hz). Visible light has a frequency close to 10^{14} cycles per second.
- c represents the constant speed of light in a vacuum: 3.0×10^8 meters per second.

If you have studied wave properties, you know that at a given wave speed, the frequency of a wave is inversely proportional to its wavelength. To convert between frequency and wavelength of light, use one of the following equations:

$$c = \lambda \times \nu \qquad \nu = \frac{c}{\lambda} \qquad \lambda = \frac{c}{\nu}$$

4a
4b
4c

EXPERIMENTAL PROCEDURES

This experiment consists of five different topics, each topic having its own background and experimental procedures. You will record important information on a data summary sheet found at the end of this experiment. The sheet is perforated, so it will be easy to remove.

Topic I—Exploring Color and Wavelength Using the Spectroscope

Background: Consider a two-dimensional wave such as a water wave or sound wave. If this wave strikes a barrier with two small slits, new waves will form on the other side of the barrier (Figure 94). These two new waves interfere with each other resulting in lines of constructive and destructive interference. When light shines through the narrow slits, regions of constructive interference appear as bright bands. Now look again at Figure 85. The mesh screen acts as a barrier with many openings.

Different wavelengths of light constructively interfere at different locations. Short wavelengths produce bright lines close to the centerline between the two slits.

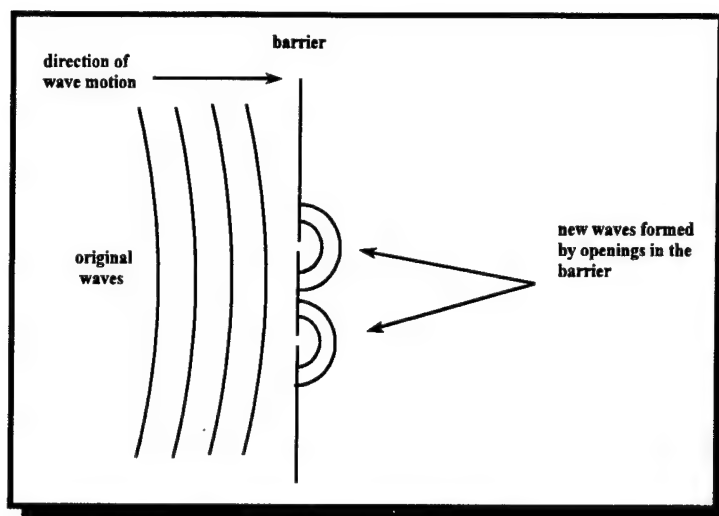


Figure 94. Waves passing through narrow slits form new wave fronts.

Longer wavelengths make bright lines further off to the side. A mixture of different wavelengths of light will produce a series of interference patterns. White light is a mixture of all colors of light. When white light is viewed through a spectroscope, the component wavelengths constructively interfere at different locations, and a multi-colored spectrum forms.

The spectroscope you will use in this experiment contains a small piece of plastic film called a diffraction grating. The grating is approximately 0.5" long and has 7,200 slits ruled on its surface. The diffraction grating is attached to one end of the spectroscope, while the other end has a slit to allow light to enter. To use the spectroscope, look through the diffraction grating end, and align the slit with the light source. You should see a spectrum projected on the numeric scale inside. See Figure 95.

The plural of *spectrum* is *spectra*.

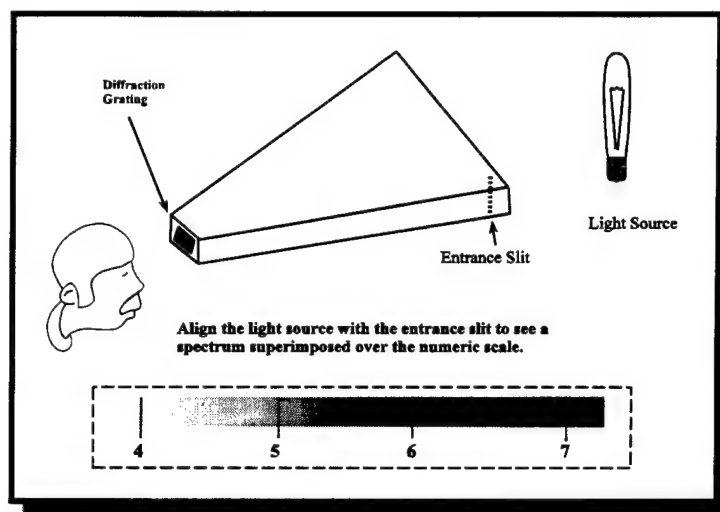


Figure 95. How to use the spectroscope.

Line Spectra and Band Spectra

You can learn a lot about a sample by looking at the light spectrum it produces. For example, gaseous samples emit different spectra than solid samples. In this section you will observe a solid light source, a gaseous light source, and a light source that uses both a solid and a gas. Continuous spectra comprised of all colors are called *band spectra*, while *line spectra* are comprised of only certain colored lines. You will determine how the spectrum of a solid source differs from the spectrum of a gaseous source.

Materials and equipment:

- spectroscope
- incandescent light
- mercury vapor light

Safety precautions:

This experiment topic only uses spectroscopes and light sources. General laboratory safety practices apply.

Topic 1 procedures:

1. Look at an incandescent light bulb through your spectroscope. Be sure to look through the narrow end of the scope, and line up the slit at the wide end with the light source. You should see a spectrum on the numeric scale.

2. Record the spectrum colors on your data sheet starting with shortest wavelength and ending with longest wavelength. You will see the shorter wavelength colors closer to the spectroscope slit, and the longer wavelength colors deflected towards the outside of the scope.
3. On your data sheet, draw an arrow above your list of colors that points in the direction of increasing frequency. Refer to equations 1a, 1b, and 1c if necessary.
4. Look at the mercury vapor lamp through your spectroscope. Compare the type of spectrum it produces with the spectrum from the tungsten lamp. Fill in the blanks for the statements on your data sheet.
5. Finally, look at the fluorescent room lights with your spectroscope. On your data sheet, compare the spectrum you see with the spectra from the tungsten and mercury lamps.

Topic 2—The Fingerprint Nature of Spectra

Background: In addition to determining if a sample is a solid or a gas, scientists can determine the identity of a sample by looking at its spectrum. Every element emits a different set of lines just like every person has a unique set of fingerprints. In this part of the experiment, you will look at different elements through your spectroscope, and record the lines you see on the atomic spectra chart provided at the end of the experiment.

Materials and equipment:

- gas discharge tubes
- Na and K solutions
- Bunsen burner

Safety precautions:

This portion of the experiment uses open flames and high-voltage gas discharge tubes. Wear safety goggles at all times.

Topic 2 Procedures:

1. The laboratory will be equipped with gas discharge tubes for various elements. Observe the emission spectra of these elements with your spectroscope and record your observations on your atomic spectra chart. Note that this chart correlates color with the wavelength of light, and the numeric scale in your spectroscope shows wavelength in 100s of nanometers.

CAUTION! DO NOT TOUCH THE GAS DISCHARGE TUBES. The discharge tubes use very high voltage electricity. If a tube is not working, ask your TA for assistance.

Look again carefully at the mercury vapor lamp, then at the spectrum of the overhead fluorescent lamp. Can you identify an element present in the fluorescent lamp?

3. The laboratory will be equipped with bottles containing sodium and potassium compounds. These bottles have corks with flame test wires mounted in them. Ignite the Bunsen burner, obtain a blue flame, and dim the classroom lights. Take the sodium flame test wire and place its loop at the hottest part of the flame.
4. Look at the flame through the spectroscope. (You may have to replenish your supply of material on the flame test wire periodically.) One lab partner should hold the flame test wire in the flame while the other partner observes the spectrum. Record the spectral lines you see on your spectra data chart.

CAUTION! DO NOT HOLD YOUR SPECTROSCOPE TOO CLOSE TO THE FLAME. The spectroscopes are plastic and will melt or catch on fire! Lab partners need to watch each other.

5. Repeat the observation described in steps 3 and 4 for the potassium solution.

Topic 3—Light as a Particle

Background: Electrons occupy positions around the nucleus of the atom in discrete energy states. Electrons can be excited to higher energy states by heating or electrical energy. They then fall back to lower energy states, emitting a photon of light. These photons contain an amount of energy equal to the difference between the two energy

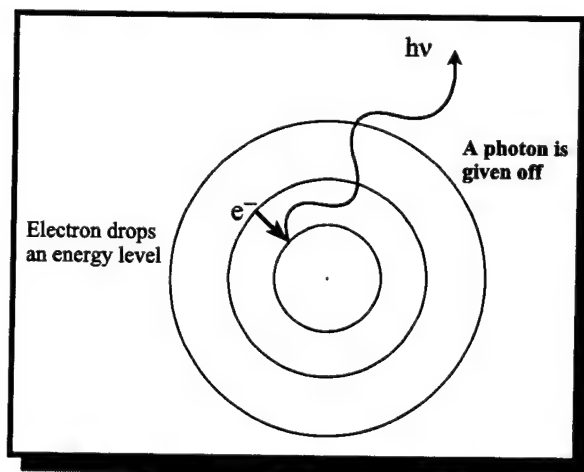


Figure 96. An electron moving from a higher to lower energy level produces light.

states. The frequency of the light emitted, then, depends on this energy difference. See Figure 96.

To explore the relationship between the energy and color of light, we will set up a simple experiment to produce light with different-colored light emitting diodes (LEDs). LEDs produce light when a voltage is applied to two electrodes that are separated by a semiconductor. When the voltage becomes great enough to promote an electron across the energy gap in the LED material, electricity will flow through the diode and it will give off light.

For this portion of the experiment, you will use the LabWorks interface. The interface's digital-to-analog converter (DAC) provides the voltage to operate the LED. The purpose of this topic is to measure the energy required to make the LED produce light.

By performing this experiment with red, yellow, green, and infrared LEDs, we should be able to find a relationship between the color or wavelength of light and the energy required to produce that light. You will use a Hewlett Packard HP 48 calculator which is connected to the LabWorks interface for this part of the experiment. When you finish taking data, you will have a data array containing wavelength and energy values. With this data you will be able to find the relationship between the color of a light and its energy.

Planck's Law and Calculating Planck's Constant

In 1900, German physicist Max Planck proposed that light energy was emitted in discrete packets called quanta. He also deduced that the energy of light was directly proportional to that light's frequency. This relationship is expressed by the simple equation

$$E = h\nu \quad (5)$$

- E is the energy of light in joules.
- ν (nu) is the frequency of the light in cycles per second.
- h is the proportionality constant, called Planck's constant: 6.63×10^{-34} J-s.

The data you get from the Planck program will allow you to calculate Planck's constant. If you take your data and convert wavelength to frequency and voltage to joules, the graph of energy versus frequency will fit Equation 5. The slope of your line will be Planck's constant!

Materials and Equipment:

- LabWorks interface
- HP 48 calculator

- HP connecting cable and nine-pin null modem adapter
- LEDs and connector cable

Safety Precautions:

General laboratory safety practices apply to the following procedures.

Topic 3 Procedures:

1. Ensure the HP 48 calculator is connected to the LabWorks interface using the HP cable and the nine-pin null modem adapter.
2. Connect the LED cable using the blue, yellow, and black DAC-1 and I-1 connections on your LabWorks interface, using Figure 97 as a guide.

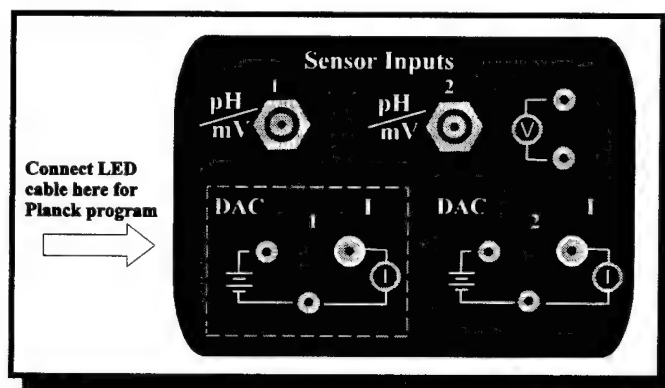


Figure 97. LED connections to the LabWorks interface for the Planck's Constant experiment.

3. Press the HP 48 key associated with the PLINI program. You should see the DAC1 and I1 LEDs on the LabWorks interface illuminate.
4. Insert one of the LEDs into the connector cable.
5. Press the HP 48 key associated with the PLNK program. When the program prompts you to enter the LED wavelength (Figure 98), enter the wavelength of the LED you have connected and press the large ENTER key on center left the HP keypad. The wavelengths of light produced by each color are listed below:



Figure 98. HP 48 LED wavelength entry.

| | | |
|---|----------|--------|
| ■ | Infrared | 880 nm |
| ■ | Red | 635 nm |
| ■ | Orange | 600 nm |
| ■ | Yellow | 585 nm |
| ■ | Green | 569 nm |

The program will increment the DAC voltage and display both current and excitation voltage. Look for the LED to start lighting up as the current increases. You will not see the light produced by the infrared LED. Why?




6. When the voltage and current display disappears, change the LED and repeat step 5 until you have measured all LEDs. Do not run PLINI again.
7. Press the HP 48 key associated with the ANLZ program. This program performs many calculations for you. Pre-lab question 1 outlines the math functions ANLZ performs. The program displays the slope, intercept, and correlation coefficient of your data. Record this experimental value on your data sheet, and calculate the percent error.
8. Graph your data using the HP 48 PLOT function. Press the green  key located just above the **ON** key, then press **8** on the keypad. The screen shown in Figure 99 should appear.
9. Choose Scatter for graph type, then press  to draw your graph.
10. To see how well your points fit a straight line, press  to run STATL and the calculator will draw a statistically fitted line through your data points.



Figure 99. HP 48 graph plot setup.

Topic 4—Identifying Unknown Elements Using Spectra

Background: It is possible to record an element's spectrum by placing a camera behind a spectroscope. Figure 100 shows a simple sketch of this set-up. When the spectrum is recorded on film instead of being viewed, the instrument is called a spectrograph rather than a spectroscope. The color slides to be used in this section of the experiment were taken with similar equipment and color film.

Each element has a unique set of spectral lines, and this set is always characteristic of a single element and no other. Topic 1 showed that it is possible to identify a sample as either a solid or a gas by observing its spectrum. In this topic you will be asked to identify unknown elements by looking at the spectrum of each.

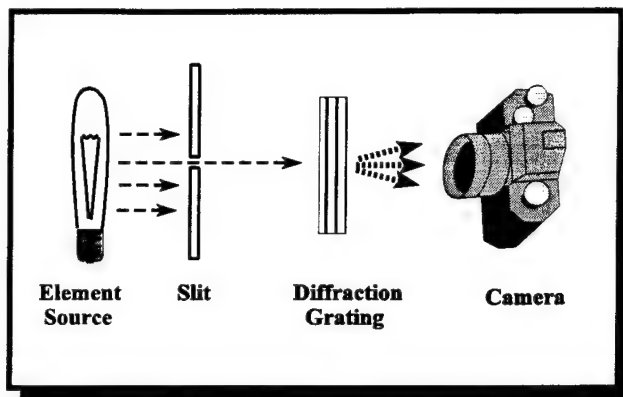


Figure 100. How spectra can be recorded on film using simple equipment.

It is difficult to determine the wavelength of the various spectral lines directly from a photograph or slide, since the camera has no calibration scale. The slides used in this experiment, however, have a known spectrum, mercury, displayed over the unknown spectral lines. You will use the mercury lines to construct a calibration graph which relates position on the scale to actual light wavelength.

You will use a computer program called Spectra, which will display the unknown spectra as well as mercury calibration lines. A screen shot from this program is shown in Figure 101.

Materials and equipment:

- Spectra software

Safety precautions:

General laboratory safety practices apply to the following procedures

Topic 4 procedures:

1. From Windows 95 double click on the Spectra icon. From the opening screen click on one of the buttons marked W, X, Y, or Z. This will bring up a screen similar to Figure 15. Record the letter of your unknown in your data sheet.
3. Double click on each of the lines in the top row. These are the mercury calibration lines. You need to click on all six calibration lines.
4. Click on the Change Mode button in the lower right corner of the screen and the calibration graph will appear in the upper window.
5. Double click on each of the unknown lines in the middle row, and the grid values of these lines will be saved in the lower box on the right side of the screen.

6. Click on the Change Mode button once more, and the grid values will be converted to nanometer values. Record these values on your data sheet.
7. After you have converted the unknown's readings to nanometers, compare these values to elements listed in Table 14. The spectral lines that match will identify the unknown elements. Record the identity of your unknown on your data sheet.
8. Repeat steps 1-7 for the remaining unknowns.

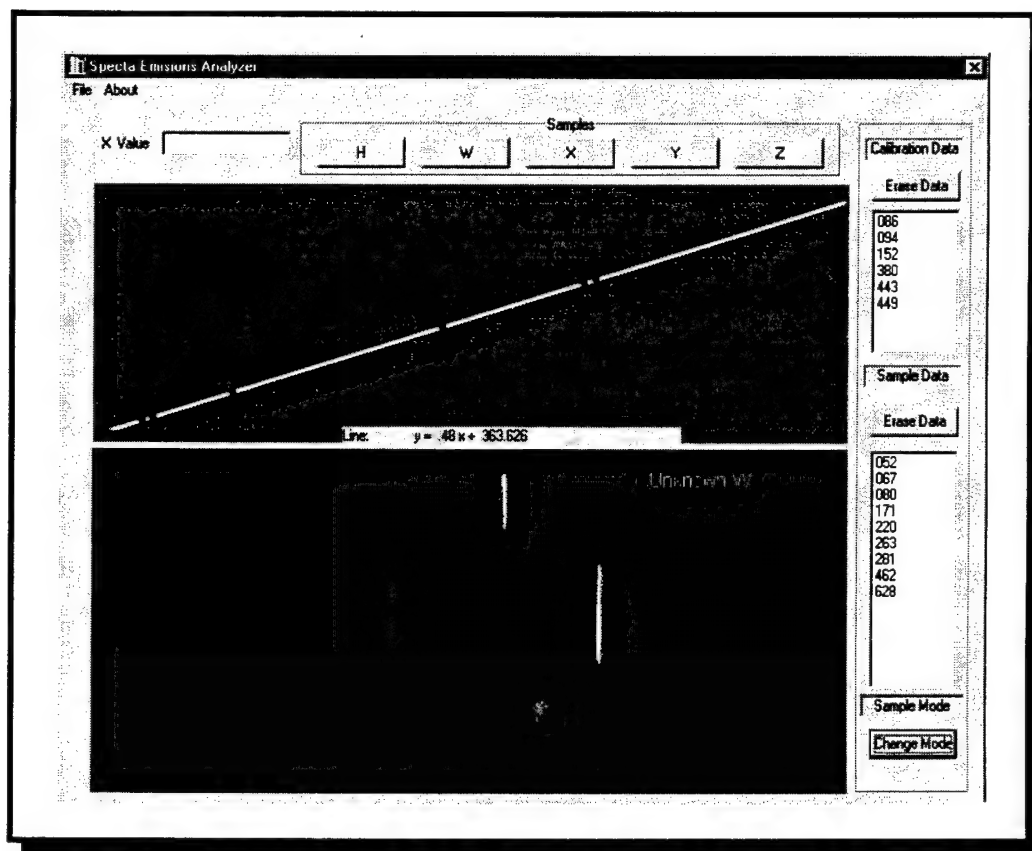


Figure 101. The Atomic Spectra program.

| Thallium | Cadmium | Hydrogen | Zinc | Helium | Sodium | Neon | Cesium | Lithium |
|----------|---------|----------|-------|--------|--------|-------|--------|---------|
| 377.5 | 467.8 | 397.0 | 384.0 | 361.4 | 466.9 | 470.4 | 388.9 | 391.5 |
| 436.0 | 480.0 | 410.2 | 468.0 | 370.5 | 498.3 | 471.5 | 455.5 | 398.6 |
| 535.0 | 508.5 | 434.0 | 472.2 | 382.0 | 514.9 | 482.7 | 459.3 | 413.3 |
| 655.0 | 643.8 | 486.1 | 481.0 | 388.9 | 515.3 | 488.5 | 524.9 | 427.3 |
| 671.4 | | 656.3 | 647.9 | 396.5 | 589.0 | 534.3 | 527.4 | 460.3 |
| | | | | 402.6 | 589.6 | 540.0 | 540.3 | 497.2 |
| | | | | 412.1 | 615.4 | 576.4 | 541.9 | 610.4 |
| | | | | 414.4 | 616.0 | 585.2 | 583.1 | 670.8 |
| | | | | 438.8 | | 588.2 | 601.0 | |
| | | | | 447.1 | | 603.0 | 621.3 | |
| | | | | 468.5 | | 607.4 | 635.5 | |
| | | | | 471.3 | | 616.4 | 658.7 | |
| | | | | 492.2 | | 621.7 | 662.8 | |
| | | | | 501.6 | | 626.6 | 672.3 | |
| | | | | 587.6 | | 640.2 | | |
| | | | | 667.8 | | 650.6 | | |
| | | | | | | 653.3 | | |
| | | | | | | 659.9 | | |
| | | | | | | 667.8 | | |
| | | | | | | 671.7 | | |

Table 14. Selected spectral lines of some common elements from CRC Handbook, 73rd edition (wavelengths are given in nm).

Topic 5—Bohr's Planetary Electron Model

Background: Niels Bohr was a Danish scientist who worked on identifying the position of electrons around the nucleus of an atom. It was known at the time that only certain colors of light were emitted by energetically excited atoms. Electrons that absorbed light moved into higher energy states, while electrons that moved from higher to lower energy states emitted light.

Applying this knowledge, Bohr proposed that electrons run in “planetary orbits” around atomic nuclei and only specific orbits existed. Bohr began his mathematical derivation by setting the electrostatic attraction between an electron and the nucleus equal to centripetal acceleration of the orbiting electron:

$$\frac{mv^2}{r} = \frac{Ze^2}{r^2} \quad (6)$$

centripetal electrostatic
acceleration attraction

The electron has a mass m and a charge e , and it is moving in a circular orbit around a nucleus of atomic number Z . The electron is distance r from the nucleus, and it is traveling at velocity v . This model is illustrated in Figure 102.

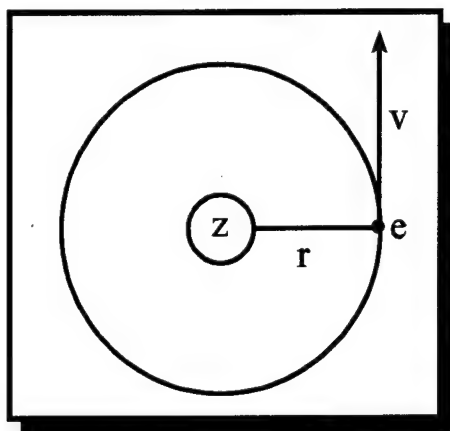


Figure 102. The Bohr model of a single-electron atom (adapted from *Douglas, McDaniel, and Alexander*)

Bohr's equation expanded to include gravitational attraction and the relationship between energy and wavelength of light. This equation predicts the wavelength of light produced as an electron falls from an outer, higher energy orbit to an inner, lower energy orbit

$$\frac{1}{\lambda} = \left(\frac{2\pi^2 m Z^2 e^4}{h^3 c} \right) \left(\frac{1}{N_1^2} - \frac{1}{N_2^2} \right) \quad (7)$$

- λ is the wavelength of light emitted by the photon as it falls from energy level N_2 to N_1 .
- h is Planck's constant (which you calculated in Topic 4).
- c is the speed of light in a vacuum: 3.0×10^8 m/s.

This model works only for hydrogen and for ions possessing a single electron. The model falls apart for multi-electron systems because Bohr neglected the wave nature of electrons.

Because we are only calculating wavelengths of light emitted by excited hydrogen atoms, all of the factors in the first set of parenthesis in Equation 7 have a value of $0.0109678 \text{ nm}^{-1}$.

The unit nm^{-1} is “reciprocal nanometers,” and it has the same value as $\frac{1}{\text{nm}}$.

Example

To demonstrate how to apply the Bohr equation, this example will calculate the wavelength of light emitted when an electron drops from the third to the second energy level.

$$\frac{1}{\lambda} = (0.0109678 \text{ nm}^{-1}) \left(\frac{1}{2^2} - \frac{1}{3^2} \right)$$

$$\frac{1}{\lambda} = (0.0109678 \text{ nm}^{-1}) (0.13889)$$

$$\frac{1}{\lambda} = 0.0015233 \text{ nm}^{-1}$$

$$\lambda = 656.4 \text{ nm}$$

All of the visible spectral lines for hydrogen are generated by electrons dropping to the second energy level. This series of emissions is called the Balmer series. Electrons dropping to the first energy level cause ultraviolet photon emission, while electrons dropping to the third and fourth energy levels cause infrared emissions.

Bohr predicted that electron jumps ending on the second orbit would produce spectral lines in the visible region of the spectrum (see Table 15).

| Hydrogen Spectral Lines | | |
|-------------------------|-----------------------------|---------------------------|
| Electron transition | Wavelength of emitted light | Color |
| 3 → 2 | 656.3 nm | Red |
| 4 → 2 | 486.1 nm | Blue-Green |
| 5 → 2 | 434.0 nm | Violet |
| 6 → 2 | 410.2 nm | Violet (difficult to see) |

Table 15. Transitions, wavelengths, and colors of hydrogen spectral lines.

Materials and equipment:

- Spectra software

Safety precautions: General laboratory safety practices apply to the following procedures.

Topic 5 procedures:

1. Start the Spectra program and click on the H button.
2. Perform steps 2-7 in Topic 4 to find the nanometer values for the hydrogen spectral lines. Record these values in the Topic 5 section of your data sheet.
3. Each of the hydrogen spectral lines represents a transition from an excited energy level to level 2. Record on your data sheet the starting level for each of the hydrogen lines.
4. The lines on the hydrogen spectrum vary in brightness. Record on your data sheet the relative intensities of the different hydrogen lines.
5. Answer the questions in the Topic 5 section of your data sheet.

Laboratory Report

Your report should include your data and conclusions derived for each of the five experimental topics. Also answer the following question:

Which of the five topics in this experiment treated light as a wave, and which treated light as a particle? Briefly justify your answers.

Spectroscopy Prelab Questions

1. The ANLZ program in Topic 5 performs many calculations quickly. For five data points it converts wavelength in nanometers to frequency and energy from volts to joules. Use the given information to perform these calculations for the red LED (635nm).
 - a. Convert this wavelength, to frequency (s^{-1}). (Hint: use equation 1a, 1b, or 1c)
 - b. 1348 mV produced $1\mu A$ of current in this LED. Convert this millivolt value to joules.

Conversion factors:

$$c = 3.00 \times 10^8 \text{ m/s}$$

$$1 \text{ nm} = 1 \times 10^{-9} \text{ m}$$

$$1 \text{ V} = 1 \times 10^3 \text{ mV} = 1.602 \times 10^{-19} \text{ J}$$

2. Calculate percent error for the experimental Planck's constant shown in Figure 11.
3. The Spectra program automates many calibration tasks that once were performed manually. One of these tasks is the generation of a calibration curve using the known wavelengths of light emitted by mercury.

- a. Use the information in Table 16 to make a calibration graph and find the equation of the line that converts grid values into nanometers.

- b. Use Table 14 and the calibration line generated in part a to identify an unknown element whose spectrum produces lines at the following grid values:

73.1 170.6
102.3 247.2

| Line Color | Grid Value | Wavelength (nm) |
|------------|------------|-----------------|
| Violet | 55 | 404.6 |
| Violet | 62 | 407.7 |
| Blue | 120 | 435.8 |
| Green | 348 | 546.0 |
| Yellow | 413 | 576.7 |
| Yellow | 417 | 579.0 |

Table 16. Mercury calibration data.

Name _____

TA _____

Spectroscopy—Experiments Using Visible Light
Data Sheet

Remove this data sheet and use it while you perform the experiments in Topics 1-5.

Topic 1—Color and Wavelength

Colors you see in the spectroscope:

Direction of increasing frequency (draw an arrow in the space below).

_____ **Increasing wavelength** →

Solid vs. Gaseous Spectra

The tungsten lamp is a _____ source which produces a _____ spectrum.

The mercury lamp is a _____ source which produces a _____ spectrum.

Record your observations concerning the spectrum of the fluorescent lamp:

Topic 2—The Fingerprint Nature of Spectra

Use the full-page spectral chart at the end of this experiment to record the spectral lines you see for each element. For each element place vertical lines at the approximate position you see them in your spectroscope. Notice that different elements show different spectra.

Element present in fluorescent lights: _____

Topic 3—The Energy of Light

LED Color:

| | | | | | |
|--|--|--|--|--|--|
| | | | | | |
|--|--|--|--|--|--|

Increasing Excitation Energy →

Y intercept: _____

Correlation: _____

Experimental value for Planck's constant: _____ J-s

Accepted value for Planck's constant: _____ J-s

Percent error: _____ %

Topic 4—Identifying Unknown Elements Using Spectra

Include your calibration graphs from this section.

| Unknown W | Unknown X | Unknown Y | Unknown Z |
|----------------------------|----------------------------|----------------------------|----------------------------|
| Spectral Lines nm value | Spectral Lines nm value | Spectral Lines nm value | Spectral Lines nm value |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| Identity | Identity | Identity | Identity |
| | | | |

Topic 5—Bohr's Planetary Electron Model

| Color of hydrogen lines from its spectral chart | H lines nm value | energy level transition | Relative brightness [†] (1-4) |
|---|------------------|-------------------------|--|
| | | | |
| | | | |
| | | | |
| | | | |

[†]1 is the brightest and 4 is the least bright

Answer the following questions on a separate piece of paper.

1. Compare the hydrogen spectral wavelengths you found experimentally to those listed in Table 15. Does Bohr's model appear to accurately predict the visible region spectral lines of hydrogen?
2. Which hydrogen line was the brightest? Which was the least bright? Compare the brightness of the spectral lines with their wavelengths.
3. Why are some of the lines brighter than others? (Hint: The answer involves the probability of electrons reaching each energy level.)

ATOMIC SPECTRA

| | 400 | 450 | 500 | 550 | 600 | 650 | 700 |
|----|-----------------|--------|------|-------|--------|--------|-----|
| | Wavelength (nm) | | | | | | |
| | UV | Violet | Blue | Green | Yellow | Orange | Red |
| | Infra-red | | | | | | |
| He | | | | | | | |
| Ar | | | | | | | |
| Ne | | | | | | | |
| Hg | | | | | | | |
| Li | | | | | | | |
| Na | | | | | | | |

COLORIMETRY AND DETERMINATION OF CHLORINE CONCENTRATION

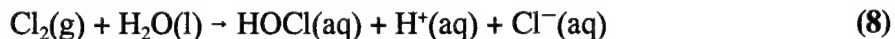
LEARNING OBJECTIVES

The objectives of this laboratory are to:

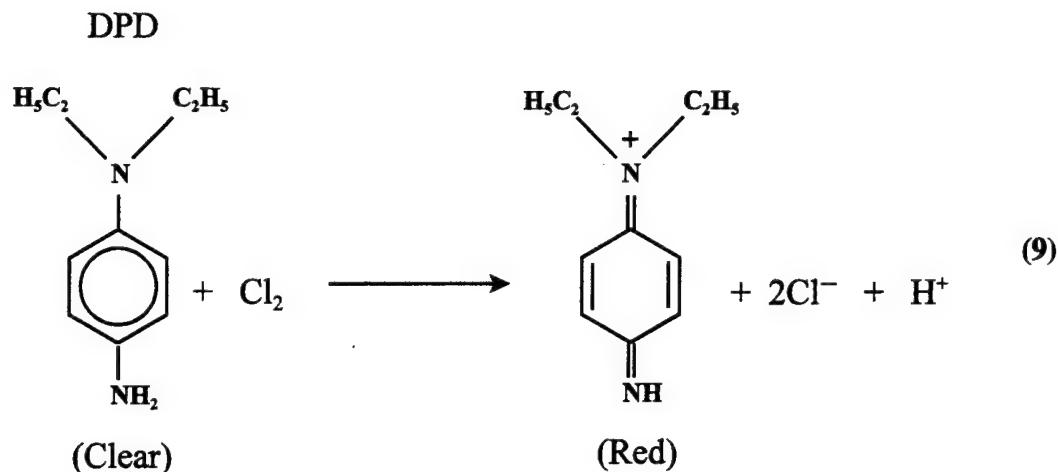
1. learn the nature of light absorption and how spectroscopy is used as a quantitative tool;
2. determine which color light source works best for measuring free chlorine concentration;
3. make a set of solutions of known concentration by dilution of a standard; and
4. calibrate and use a colorimeter to find chlorine concentration in tap water.

BACKGROUND

Most municipal water treatment systems use chlorine to kill harmful bacterial that can grow in drinking water. The amount of chlorine used needs to be enough to kill the bacteria, but too much chlorine makes drinking water taste bad. Water treatment plants need to add the correct amount of chlorine to the water. The reaction of chlorine gas with water occurs as follows:



Chlorine is also added to swimming pools to make the water safe for swimming. Some swimming pool test kits test for chlorine using N, N-diethyl-p-phenylene diamine, called DPD. DPD is a chemical indicator that turns red in the presence of chlorine by the reaction illustrated by Equation 8. Colorimetry uses the light-absorbing properties of the product of this reaction to find the concentration of chlorine in the solution.



Color is a natural phenomenon that many of us take for granted. We are concerned about the color of our clothing or the color of our cars, but we seldom stop and think about the many uses of color. Traffic lights and signs depend very much on color to communicate important messages to people. Scientists also use color to obtain information from different chemical compounds. The area of science that concerns reading the light absorbed or reflected by a substance is called spectroscopy. The subset of spectroscopy that involves visible light is called colorimetry. You may have already used spectroscopy to find the identity of unknown elements. Finding the identity of a substance is a *qualitative* experiment. In this experiment you will use light to find how much free chlorine exists in a sample of tap water. Finding the amount is a *quantitative* experiment. How can light tell us the amount of chlorine in our sample? To begin, let's discuss what causes the colors that we see.

Qualitative—What is there?

Quantitative—How much is there?

Color Formation, or "Why is the Sky Blue?"

Many people mistakenly believe that colors are emitted by colored substances. In fact, the opposite is true. White light is a combination of all the visible colors, red through violet. The paper on this page appears white because it reflects all of the visible colors and absorbs none. The ink on this page is black because it absorbs all colors and reflects none. The paint on a stop sign is red because it absorbs all the colors in white light

except red (Figure 103). The same principle is true for the sky. Some of the light from the sun becomes scattered by the Earth's atmosphere. During this scattering process, air molecules absorb all colors except blue.

We see color, therefore, because materials all around us absorb some of the components that make up white light. What happens during this absorption? Where do the colors "go"?

You may already know that light is made up of extremely small packets of energy called *photons*. Photons interact with the electrons that surround atoms, causing these electrons to "jump" to a higher energy level. If the energy of the photon matches the difference between two energy levels, the photon will transfer its energy to the electron. This extra energy causes the molecule that absorbed the photon to rotate or vibrate more vigorously until the excess energy dissipates. We feel these molecular vibrations as heat. That is why dark objects (ones that absorb a lot of light) become hot when they are placed directly in sunlight.

Percent Transmittance and Absorbance

How can scientists use this selective absorption of photons to find solution concentrations? Figure 103 shows how light is absorbed when it reflects off of a surface. Certain colors of light may also be absorbed when shown through a translucent substance, such as a solution.

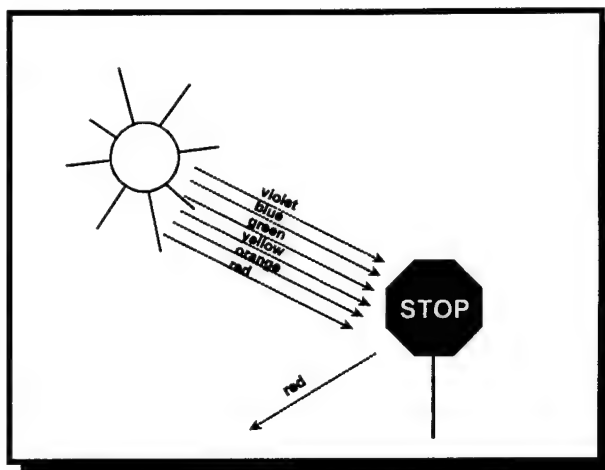


Figure 103. A stop sign appears red because it absorbs some wavelengths of light.

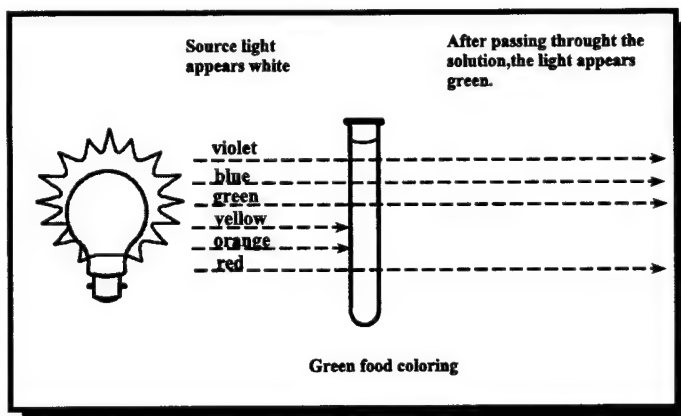


Figure 104. Some wavelengths of light are absorbed as they pass through green food coloring.

In Figure 104 a white source light shines through a solution of green food coloring.

Molecules in the solution absorb yellow and orange wavelengths of the source light, making it appear green after it passes through the solution. If a light sensor is placed on the opposite side of the light source, the sensor could measure how much light was cut

out by the solution. The more concentrated the solution, the more light would be absorbed.

Scientists describe the interaction of a solution with light in terms of *percent transmittance*. Percent transmittance refers to how much of a certain color of light gets through a solution.

Distilled water has 100% transmittance, while an opaque block has 0% transmittance. The light sensor you will use in this experiment contains a semiconductor that

produces electrical current based on how many photons strike its detector. Because of this fact, the light sensor measures percent transmittance directly. If more photons pass through the solution and strike the light sensor, more electrical current flows.

A note about color mixing. Mixing colored lights does not produce the same result as mixing colored pigments. When all visible colors of light combine, the result is white light. When the those same colored inks or paints mix, the result is a murky brown.

Suppose we have three identical vials of a substance that have 50% transmittance of the source light. In Figure 105a, one vial is placed in front of the light, and half of the source light shines through the vial. A second vial is placed next to the first in Figure 105b, and 50% of the *remaining* light is cut out, making the total percent transmittance of two vials placed side-by-side 25% (not 0% as you might expect). In Figure 105c, a third vial reduces the remaining light by half, and now 12.5% of the original light is being transmitted.

A table of percent transmittance for 0-4 of vials, as well as a graph of this data, is shown in Figure 106.

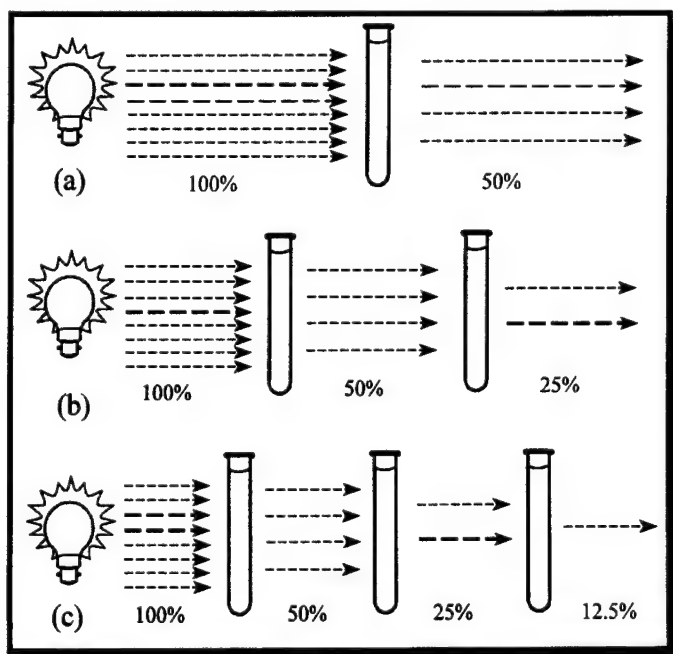


Figure 105. The effects of placing different numbers of fifty percent light-transmitting vials in front of a light source.

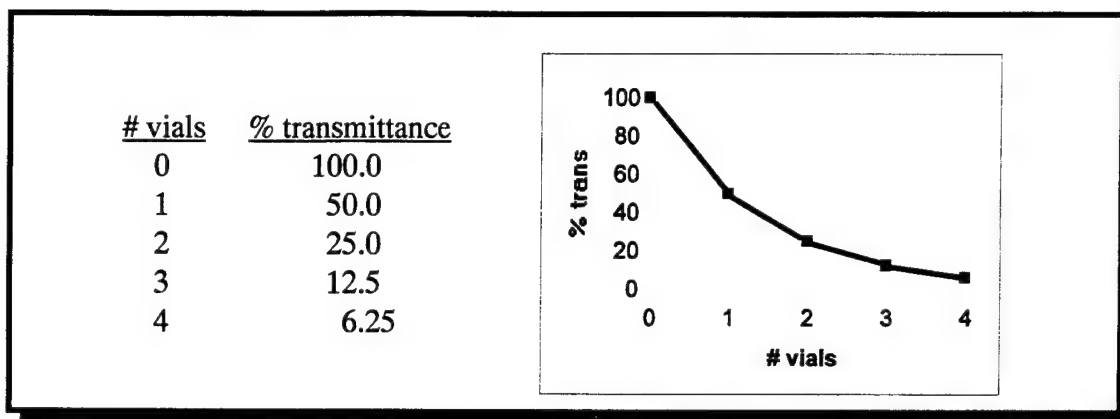


Figure 106. Percent transmittance does not vary linearly with amount of absorbing material.

The raw data does not make a straight line. It would be very difficult to fit this data to a linear equation and then predict what the percent transmittance would be for a solution of unknown concentration. We need to perform a curve fit to find the function that allows us to express percent transmittance as a straight-line function. Chapter 9 of *Measurement: The Basic Science* discusses how to fit nonlinear data into a format that allows a straight-line plot.

By taking the logarithm of percent transmittance and multiplying this value by -1 , we get an exact linear relationship between light and the amount of absorbing substance in the light path. Scientists have given the name *absorbance* to the quantity $-1 \times \log(\text{percent transmittance})$. Figure 107 shows what the data in Figure 106 looks like when percent transmittance is converted to absorbance.

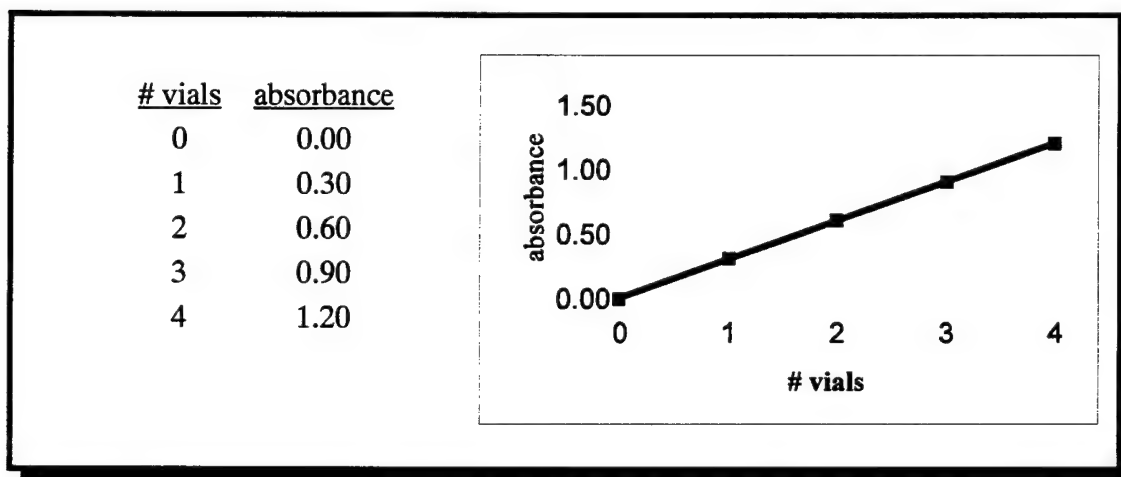


Figure 107. Absorbance shows a linear relationship to amount of obstructing material.

Percent transmittance is easier to measure, but absorbance is directly related to a solution's concentration by a relationship known as Beer's Law. In this experiment you will measure percent transmittance, convert that quantity to absorbance, and then use absorbance to find the concentration of your unknown solution. In equation form, Beer's Law is:

$$A = \epsilon \cdot l \cdot c \quad (10)$$

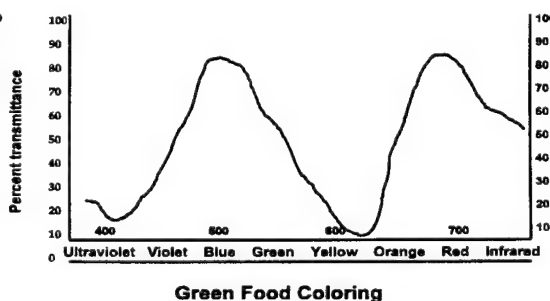
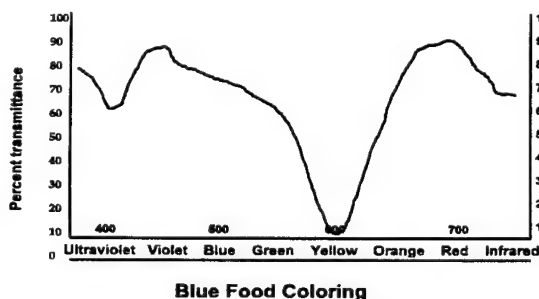
- A is the solution's absorbance (usually converted from percent transmittance).
- ϵ is the solution's molar absorptivity (a property that is different for different solutions and different light colors).
- l is the cell path length, or the distance through the solution that the light travels.
- c is the solution's concentration.

Choosing the Right Light Source

The solution described in back Figure 101 appears green because it absorbs the yellow and orange parts of white light. Given this information, which color light source would be the best to use in a colorimetry experiment on a green solution? To answer this question, the light source needs to be a color that the sample *absorbs*. The amount of light reaching the detector will then be very sensitive to changes in the sample concentration.

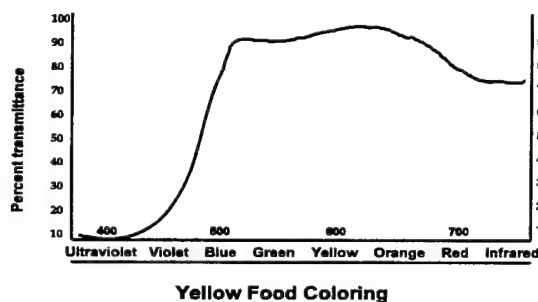
On the other hand, if you use a light source that is not absorbed, but rather transmits through the sample, changing the sample concentration will not change the amount of light that reaches the detector. For example, if the sample solution is red, a red LED is not a good color for a light source.

In the first part of the experimental procedures, use the following percent transmittance charts to help you determine which color light source you want to use. The food coloring practice solution, as well as the treated chlorine solutions, will be red. You need to determine which light source color does not transmit through a red solution.

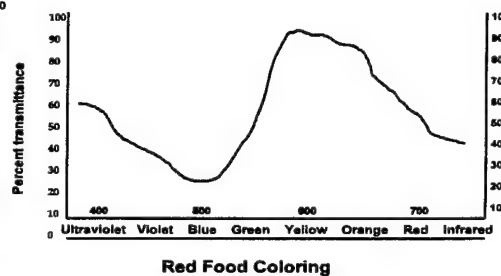


Spectral Chart 1

Spectral Chart 2

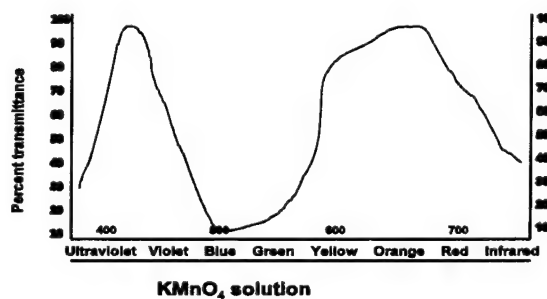


Spectral Chart 3



Spectral Chart 4

How to read the charts. The parts of the curve that reach the top of the chart represent colors that go through the solution with 80-100 percent transmittance. Parts of the curve that don't go very high represent colors that are absorbed by the solution (0-10 percent transmittance). For example, Spectral Chart 1 shows the spectral transmittance of a blue food coloring solution. This particular dye transmits blue, green, and red very well. The region of color around yellow and orange do not transmit well at all; these colors are absorbed by this solution. If you wanted to perform a colorimetry experiment on a blue solution, you would want to use a light source that was yellow-orange in color.



Spectral Chart 5

MATERIALS AND EQUIPMENT

- LabWorks interface
- HP 48 calculator and connecting cable
- Wood block colorimeter, including phototransistor, LEDs, and cuvette
- Standard and unknown food coloring solutions
- Standard chlorine solution

SAFETY PRECAUTIONS

General laboratory safety practices apply to the following procedures. Wear eye protection at all times.

EXPERIMENTAL PROCEDURES

Following is an overview of the tasks you will accomplish during this laboratory:

Set up experiment:

1. Choose your LED color.
2. Connect your colorimeter and HP 48 to the LabWorks interface.
3. Calibrate your colorimeter using the CALCO calculator program.

Practice using food coloring:

4. Make a set of food coloring standard solutions.
5. Measure the absorbance of the standards using the MEAS program.
6. Find the concentration of the unknown using the UKN program.

Solve the application problem:

7. Make a set of chlorine stock solutions.
8. Repeat steps 5 and 6 to find the chlorine concentration in tap water.

Choosing Your LED Color

Look at five the Spectral Charts. Use that data to create a hypothesis concerning which LED color will be the best choice to use for your colorimetry experiments. How could you test your hypothesis? Discuss this question with your lab partner and other lab groups, and devise a simple method to experimentally determine which LED color would work best for colorimetry on a red food coloring solution.

Connecting the Colorimeter to the LabWorks Interface

Plug the phototransistor cable into DAC1 and I1 of the LabWorks interface, and insert the plugs of the LED cable into the green and white Output 1 posts. These points are highlighted in Figure 108. Insert the phototransistor into one side of the wood block, and the LED that you want to use in the other side. Make sure the LED and phototransistor are directly across from each other. Plug the hole on the side of the wood block with a rubber stopper.

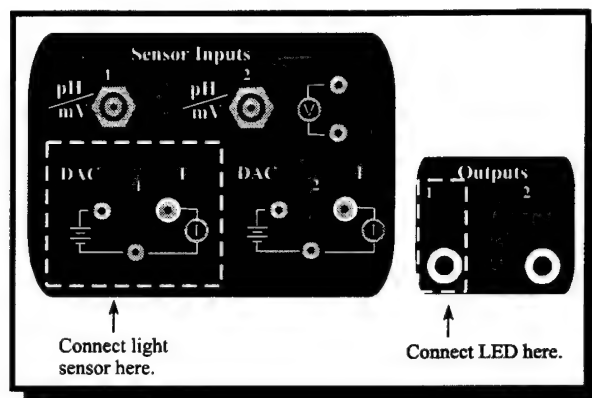


Figure 108. Light sensor and LED connecting points for colorimetry.

Calibrating the Colorimeter

1. Make sure the LabWorks interface has power, and the calculator and colorimeter are connected.
2. Press the button on the HP 48 that is located below the CALCO program.
3. The program will prompt you to insert a cuvette of distilled water in the colorimeter and press OK. Be sure to cover the cuvette with the film cannister before taking the reading.

A note about cuvettes. Some cuvettes have two clear sides and two opaque sides. Handle the cuvettes using the opaque sides, and make sure the colorimeter light shines through the clear sides. Wipe any smudges, water drops, or fingerprints from the clear sides with a Kimwipe before calibrating or making measurements.

4. After pressing the key below OK, you will see a series of microamp (μA) readings displayed in the calculator window. If this number is close to 0, check to see that your LED is lit.

5. When the Calibration OK screen appears, you are ready to start making measurements. Save this cuvette to make your first reading in the next part of the experiment.

Practice Using Food Coloring

The next part of the experiment involves making standard solutions and measuring absorbance. You will make a calibration graph that equates absorbance to solution concentration. For the food coloring solutions, use the concentration unit “parts per 10 mL of solution.” Make up your standards with a 10-mL graduated cylinder and a dropper. Table 17 shows the portions of water and standard used to make these solutions. Be sure to clearly label the containers that hold your solutions. After making the solutions, measure them in the colorimeter using the following amounts of food coloring and water:

| mL food color | mL water | Concentration |
|---------------|----------|---------------|
| 0 | 10 | 0 parts/10 mL |
| 2 | 8 | 2 |
| 4 | 6 | 4 |
| 6 | 4 | 6 |
| 8 | 2 | 8 |
| 10 | 0 | 10 |

Table 17. How to mix standard solutions.

6. Make sure the cuvette with distilled water is still in the colorimeter. Activate the MEAS program in the HP 48 calculator. The first screen you see will prompt you to enter the concentration. For the distilled water solution press **0**, and then the **ENTER** key on the left side of the keypad.
7. The colorimeter will take readings for a few seconds, and then the program will prompt you to either take another measurement or quit. You will take more readings, so press **1** on the numeric keypad, then **ENTER**.



8. Empty the distilled water from the cuvette and rinse with a few milliliters of the 2-parts-per 10 solution. Fill the cuvette two-thirds full of the 2-parts-per-10 solution, wipe off any residue on the outside of the cuvette, and place the cuvette in the colorimeter. Make sure the light cover is on and colorimeter light shines through the clear sides of the cuvette.
9. When the "Enter solution concentration" screen appears again, press **2**, then **ENTER** for the concentration and let the colorimeter read. Press Choose **1**, then **ENTER** from the repeat or quit screen to take another reading.
10. Repeat steps 8 and 9 for the rest of your standard solutions, each time rinsing the cuvette with the next solution about to be read. Be sure to enter the correct concentration for each solution.
11. When all standard solutions have been measured, press **2**, then **ENTER** from the repeat-or-quit screen to exit the program.
12. To find the concentration of the food coloring unknown, rinse the cuvette with a few mL of the unknown solution, fill the cuvette two-thirds full of unknown, and place the cuvette in the colorimeter.
13. Press the HP 48 key associated with the UKN program. This program measures the absorbance of the unknown and finds its concentration using the calibration data you obtained in steps 4-6.
14. When the program finishes running, the calculator will display a screen similar to Figure 109. The slope, intercept, and correlation are for your calibration line. (A correlation close to 1 means you have a good calibration line.) The concentration listed is the concentration of your unknown solution. Record this information on your data sheet.
15. Graph your data using the HP 48 PLOT function. Press the green  key located just above the **ON** key, then press **8** on the keypad.
16. Choose Scatter for graph type, then press  to draw your graph.



Figure 109. Information obtained from HP 48 analysis program, UKN.

17. To see how well your points fit a straight line, press \square_b to run STATL and the calculator will draw a statistically fitted line through your data points. Print this graph using the infrared HP printer.

Application—Determining Chlorine Concentration in Tap Water

The procedures used to find the chlorine concentration of tap water are almost identical to the procedures used to find the unknown food coloring solution. The only difference is you will make 40-mL standard solutions, and you will treat your samples with a DPD #1 tablet to make the solutions visible to the colorimeter. Make your chlorine standards using the following procedures:

1. Using the 3 ppm standard chlorine solution provided, make four dilutions similar to the food coloring dilutions you made in the first part of this experiment. In contrast to the food coloring solutions, each solution you make must be 40 mL. Your data sheet will help you make the solutions. Record the volume of standard solution added, the volume of water added, and the resulting concentration. Be sure to use deionized water to make your solutions.
2. After diluting the standard solution, you should have six solutions to measure: the undiluted chlorine standard, four dilutions, and pure deionized water. Keep each solution in a well-marked container.
3. Add one DPD tablet to each solution (but not to the deionized water). Swirl or stir each solution to make sure the tablet completely dissolves, and let the solutions stand for about 5 minutes. The solutions should turn various shades of red, depending on the amount of chlorine in each solution.
4. Fill a cuvette two-thirds full of deionized water, and calibrate the colorimeter using Step 1 of the food coloring procedures.
5. Use the MEAS program to colorimetrically read each solution.
6. While one lab partner measures the standards, the other can obtain a tap water sample. Run the cold water tap for 3-5 minutes, and measure out 40 mL of tap water. Add one DPD tablet, stir, and let sit for 5 minutes.
7. Fill the cuvette two-thirds full with the treated tap water and measure using the UKN program. Record all pertinent information on your data sheet.

COLORIMETRY PRE-LAB QUESTIONS

Answer the following questions on a separate sheet of paper.

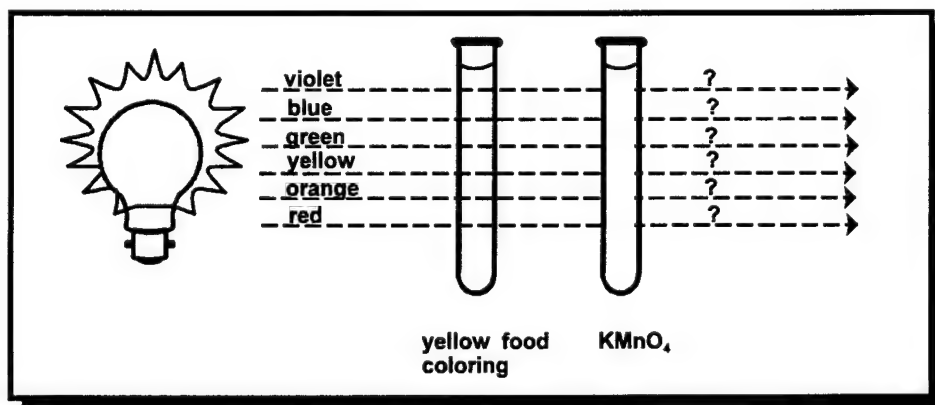
1. The MEAS and UKN programs perform many tasks automatically. Some of these tasks include converting percent transmittance to absorbance, and finding the equation of the calibration line. Given the following percent transmittance information, convert to absorbance, find the equation of the calibration line, and using this information, find the concentration of the unknown solution.

Standard Solutions

(Unknown % Transmittance: 79.3)

| Conc. (ppm) | % Trans. |
|-------------|----------|
| 1 | 92.0 |
| 2 | 83.5 |
| 3 | 76.5 |
| 4 | 70.0 |
| 5 | 63.8 |

2. A light shines through both a vial of yellow food coloring and a vial of purple potassium permanganate solution. Refer to the appropriate Spectral Charts to help you answer the following questions:
 - a. The vial of yellow food coloring absorbs which colors?
 - b. The KMnO_4 solution absorbs which colors?
 - c. Which colors transmit through both solutions?



3. White light contains a mixture of all visible colors. Why couldn't a white light source then be used for all colorimetry experiments?
4. Equation (1) on the first page of this experiment shows the reaction between chlorine gas and water to form hypochlorous acid, HClO . Equation (2) on the next page shows DPD reacting with Cl_2 to form the red-colored dye. Both Cl_2 and HClO oxidize DPD in the same manner. Write a balanced chemical equation showing the reaction of DPD with HClO .

[illegible]

Tap Water Reading

Calibration line information:

Slope: _____

Intercept: _____

Correlation: _____

Chlorine
Concentration: _____ (mg/L)

USING TURBIDITY TO FIND SULFATE CONCENTRATION

LEARNING OBJECTIVES

The goals of this experiment are to:

1. understand the importance and applications of turbidity measurement;
2. make a calibration graph by measuring turbidity of standard solutions; and
3. find the sulfate concentration of an unknown solution by measuring turbidity.

BACKGROUND

The purity of drinking water is an issue that concerns all of us. Many recent news articles and proposed legislation have been devoted to the subject of clean water. Despite the controversy surrounding clean water, very little discussion is devoted to how to determine whether water is clean or contaminated. This experiment will explore simple nephelometry and ratio nephelometry, two techniques used to quantify water quality.

Turbidity in water or other liquid is defined as the opposite of clarity. Scientists measure turbidity by shining light through a sample of water or some other liquid. If the sample is clear, the light shines straight through. If impurities such as silt, clay, or living organisms are present, then light will scatter off of these particles instead of passing straight through the solution. A greater concentration of impurities causes more light to scatter and less light to pass through. Milk is an example of a turbid solution. Fat particles suspended in milk cause light to scatter and not shine through. The process of measuring light shining straight through a solution is called *turbidimetry*, while measuring the amount of scattering light is called *nephelometry*.

The first device used to measure turbidity was called the Jackson Candle Turbidimeter. This device used a glass cylinder and a candle flame. The person measuring turbidity recorded the depth of liquid required to obscure the candle flame into a uniform glow. Measuring turbidity in this way was a good start, but the method suffered from limitations. The quality of the readings depended greatly on the skill (and eyesight) of

the person making measurements, and it was very difficult to measure very small amounts of impurities.

Modern turbidity measuring devices use lamps, light-emitting diodes, or lasers as light sources, and electronic photo cells as the light sensors. A simple nephelometer, shines a light on the sample and measures the amount of light that scatters 90° to the source path.

In simple nephelometry light scatters in all directions, not just at right angles to the light source. The amount of scattered light that reaches the detector is just a fraction of the total source light, making this a challenging technique for measuring very small concentrations. A more sensitive (and more complicated) method for turbidity measurement is called ratio nephelometry. A ratio nephelometer uses two light sensors to measure both scattered and transmitted light. Colorimetry studies have demonstrated that transmitted light is a logarithmic quantity. Ratio nephelometry, then, involves the reflected light signal divided by the logarithm of the transmitted light signal.

SAFETY PRECAUTIONS

General laboratory safety precautions apply to this experiment. Be sure to wear goggles at all times.

MATERIALS

Reagents:

- 3.0×10^{-4} M magnesium sulfate solution
- 0.10 M barium nitrate solution

Equipment

- LabWorks interface and HP 48 calculator
- wood block colorimeter
- infrared light-emitting diode (LED)
- phototransistors (2)

EXPERIMENTAL PROCEDURES

You will make turbidity measurements using the LabWorks wood block colorimeter. Light sensors will be placed in a direct line and at 90° to the light source.

Experiment Set-up and Data Acquisition

1. Assemble the LabWorks turbidimeter. Connect phototransistors to DAC1-I1 and DAC2-I2 inputs on the interface. Make sure that the scattered light sensor is plugged into DAC1-I1 and the transmitted sensor is plugged into DAC2-I2. Attach the infrared LED to the green and white Output 1 jacks. Refer to Figure 110.

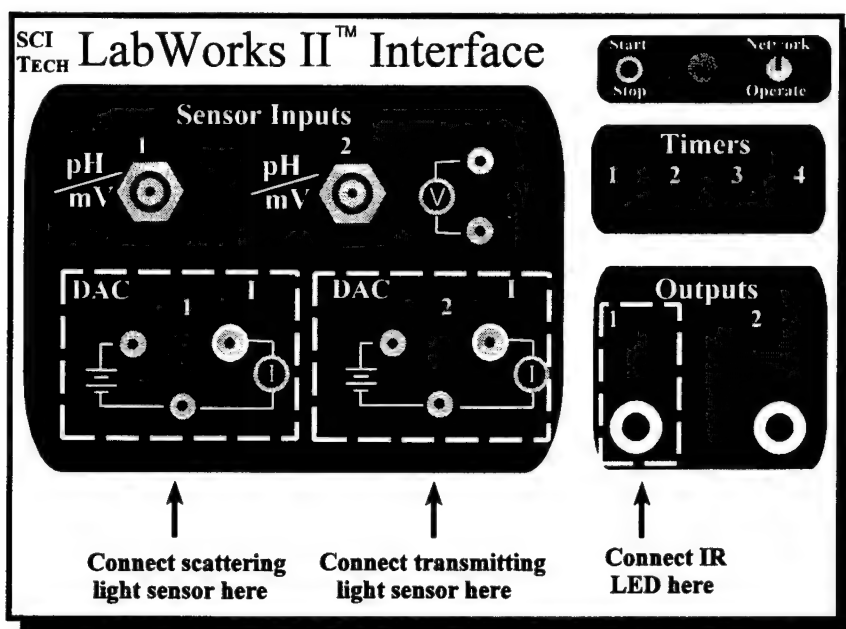


Figure 110. Connecting points for light sensors and LED for turbidity measurements.

2. Attach the HP 48 calculator to the LabWorks interface using the four-pin-to-nine-pin cable, and the nine-pin null modem adapter.
3. Make six solutions with the MgSO_4 standard using the information in Table 18. Make sure to clearly label the beakers containing your solutions.
4. Add 2 mL of $\text{Ba}(\text{NO}_3)_2$ to all solutions containing MgSO_4 and mix well. Do not add any $\text{Ba}(\text{NO}_3)_2$ to the pure water.

5. Initialize your turbidimeter by pressing the button on the HP 48 calculator corresponding with the TURIN program.
6. Fill a cuvette with deionized water, wipe the outside of the cuvette with a Kimwipe or soft cloth, and place the cuvette in the turbidimeter.
7. Record the concentration of the solution on your data sheet. (For deionized water, the concentration is 0.) Press the RDTBD button on the HP 48. Information similar to that displayed in Figure 111 will appear in the calculator display. Record this data on your data sheet. Note: The transmitted signal should be much larger than the scattered signal. If the opposite is true, you need to change the positions of your light sensors. Press any key on the keypad to clear the display.
8. Repeat steps 6 and 7 for each of the standard solutions you made. Thoroughly stir each solution before filling your cuvette. Make your readings quickly before the suspended particles settle.
9. Obtain 10 mL of a solution containing an unknown amount of sulfate. Add 2 mL of barium solution, and mix well. Fill your cuvette about two-thirds full of this solution, and measure its turbidity using the RDTBD program. Record the measured values in your data sheet

| mL MgSO ₄ solution | mL water | Concentration (M) |
|-------------------------------|----------|----------------------|
| 0 | 10 | 0 |
| 2 | 8 | 6.0×10^{-5} |
| 4 | 6 | 1.2×10^{-4} |
| 6 | 4 | 1.8×10^{-4} |
| 8 | 2 | 2.4×10^{-4} |
| 10 | 0 | 3.0×10^{-4} |

Table 18. How to mix standard MgSO₄ solutions.

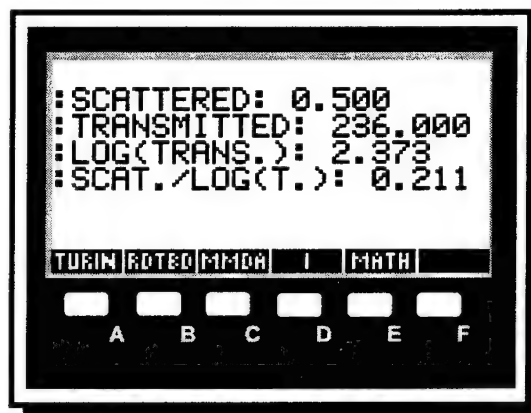


Figure 111. Data obtained from turbidity measurement displayed on HP 48 screen.

Data Analysis

10. Copy the data for the scattered signal, scattered/log(transmitted), and solution concentration to the data analysis page.
11. Use the LabWorks spreadsheet or another graphical analysis tool to find the slope, intercept, and correlation coefficient for the concentration versus scattered signal data and concentration versus scattered/log(transmitted) data. If possible, print these two graphs.
12. Use the scattered signal reading for the unknown solution and the equation of the concentration versus scattered signal line to find the concentration of the unknown solution. Perform the same calculation using the unknown's scattered/log(transmitted) value and the equation for concentration versus scattered/log(transmitted).
13. Find the actual value of the unknown's concentration from your instructor, and calculate percent error for both methods.

Answer the following questions in your laboratory report:

1. Which graph produced better results?
2. The simple nephelometer measures only the light that scatters 90° off of a sample, while the ratio turbidimeter requires two sensors. Which device is more appropriate for measuring sulfate concentration? Explain your reasoning.
3. Are the extra equipment and calculations used in ratio turbidity measurements necessary for measuring sulfate? Explain your reasoning.

Acknowledgments

Special thanks to Ted Mussard and Melinda Riley who helped me obtain the LabWorks turbidimeter reference data.

Name _____

TA _____

Using Turbidity to Find Sulfate Concentration
Pre-Lab Questions

1. Why was the Jackson Candle Turbidimeter not practical for measuring very small amounts of impurities in a sample? (Hint: Do not think of chemical principles for to answer this question. Think of a practical limitation.)

2. Why must the logarithm of a transmitted light signal be used to make the calibration line? What spectroscopic principle is being applied here?

Name _____

TA _____

Using Turbidity to Find Sulfate Concentration
Data Sheet—Data Acquisition

Standard Solutions

| Concentration | Scattered Signal | Transmitted Signal | Log(Transmitted Signal) | $\frac{\text{Scattered}}{\text{Log(Transmitted)}}$ |
|---------------|---------------------|-----------------------|----------------------------|--|
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

Unknown Solution

| Concentration | Scattered Signal | Transmitted Signal | Log(Transmitted Signal) | $\frac{\text{Scattered}}{\text{Log(Transmitted)}}$ |
|---------------|---------------------|-----------------------|----------------------------|--|
| | | | | |

Data Analysis**Standard Solutions**

| Scattered Signal | Concentration | | $\frac{\text{Scattered}}{\text{Log(Transmitted)}}$ | Concentration |
|------------------|---------------|--|--|---------------|
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

Slope: _____

Intercept: _____

Correlation: _____

 Predicted
 value for
 unknown
 concentration: _____

 Actual value
 for unknown
 concentration: _____

Percent error: _____

ENERGY-ENVIRONMENT SIMULATOR

LEARNING OBJECTIVES

The objectives of this experiment are to:

1. observe how the energy-environment simulator models the relationship between our energy supply and the rate at which we use energy; and
2. understand the problems associated with uncontrolled growth, while the amount of nonrenewable resources stays constant.

BACKGROUND

During this experiment, you will have a unique opportunity to spend time with the Energy-Environment Simulator, or Energy Sim. The Energy Sim is a computer program that was developed at Montana State University. It is used to educate people about energy supply, energy demand, and the environmental impact of our energy choices.

We often take for granted the availability of energy in the United States. Think for a minute about our lifestyles. How many cars does your family own? How many TVs, VCRs, stereos, and kitchen appliances do you use? Now consider this fact: The United States contains only 5% of the world's population, but uses 25% of the world's energy. This experiment is not meant to preach gloom and doom, but rather to open your eyes to the current state of our energy supplies, our present rate of energy consumption, and what we can expect for the future if our current energy consumption continues.

You may already be familiar with other computer simulations like war games, Sim City, or flight simulators. Simulators allow you to test solutions to problems without actually making the changes or damaging the equipment (or yourself!). For example, a flight simulator allows you to practice landings, but you do not destroy the "aircraft" or injure yourself when you crash or run the simulator off the runway.

The Energy-Environment Simulator will show you the effects of our current demand for energy on our supply of nonrenewable resources. You will also see the environmental impact of using one source of energy versus another, and you will have an opportunity to make choices concerning the distribution of our energy supply. You will decide which resources we can use, how fast we can use them, if new technology can help us, and how our lifestyles may have to change to make our energy last. If you destroy the world while the simulation is running, all you have to do is reset and try again. Hopefully, this energy simulator lesson will inspire you to think of ideas that will help extend our resources, contribute to the improvement of our environment, and ultimately, help ensure our survival.

Understanding the Simulator Screen

To make the most of your time with the Energy Sim, you need to know what each part of the Energy Sim screen represents. After you learn what the different boxes mean, you will learn how to run the simulation. Figure 112 shows the Energy Sim's main starting screen.

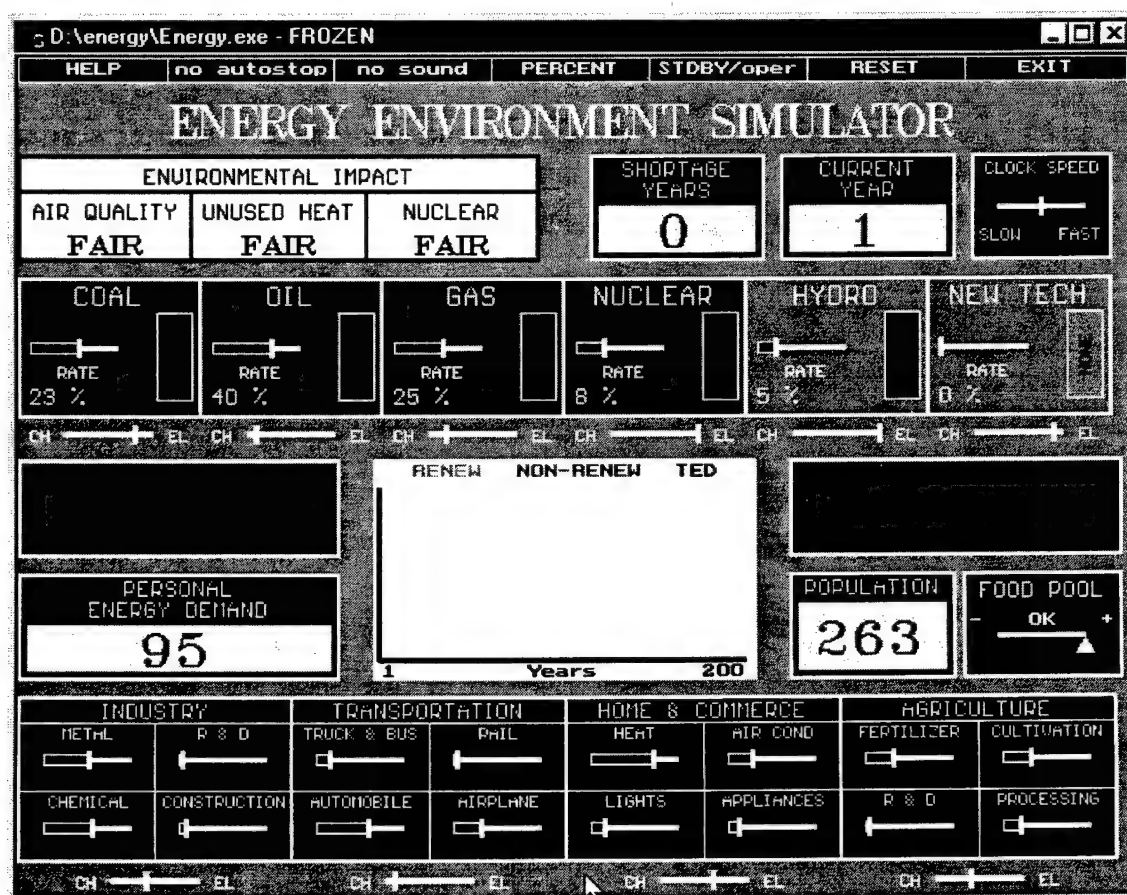


Figure 112. Energy-environment simulator main screen.

The Energy Simulator Explained

The Energy Simulator main screen displays a lot of information simultaneously. Fortunately, similar types of information are grouped together. The first part of the screen explained is located in the upper left corner, and is titled Environmental Impact.

The Environmental Impact display is divided into three areas: Air Quality, Unused Heat, and Nuclear. Air Quality reflects the amount of pollution in the air, and it gets bad when you use a lot of coal or fossil fuels to produce energy. Unused Heat pollution occurs when a company pumps water out of lakes or streams for cooling, and then returns the water 5-10° warmer. Warm water cannot support as much dissolved oxygen as cold water, so fish die when the water heats up too much. Nuclear pollution refers to the amount of nuclear waste that builds up when many nuclear power plants are used generate electricity.

The three Environmental Impact blocks turn different colors depending on how you choose to produce energy. When the blocks are green, you are not affecting Mother Nature very much, and all the Earth First! activists are happy. If you increase energy production using polluting energy sources, these squares change to yellow, then red. Your world will not be a nice place to live if you ignore the environment when making energy production choices.

To the right of the Environmental Impact blocks is a block marked Years. When the Simulator runs, this block displays the elapsed time in game years. The Simulator objective is to have people live as long as possible in their present lifestyle. The available resources must last as long as possible but it is unrealistic to think that we can reduce our energy demands all at once. The Clock Speed block, located to the right of Years allows you to adjust the rate of time passage. When things get busy, you will want to slow the Simulator down.

Underneath Environmental Impact are six blocks that represent your different sources of energy. The simulator's programmers have given you the world's entire supply of coal, oil, natural gas, nuclear and hydroelectric power plants. The four energy sources on the left are nonrenewable—once these supplies are gone, we won't get more in our lifetime. Hydroelectric power is clean, and renewable, but there are only so many rivers we can dam to exploit this energy source. New Technology represents new energy sources such as solar, wind, and geothermal energy. These energy sources are not commercially viable right now, but with research and development, they can be long-lasting, environmentally friendly energy sources.

White slide bars are located under each energy source block. These slide bars allow you (in some cases) to allocate energy resources to the production of electrical or chemical

energy. Coal, oil, natural gas, and new technology may be used to produce either type of energy. Nuclear and hydro power can only produce electricity, so those slide bars do not function.

The chemical and electrical energy pool displays are located underneath the six energy source blocks on the left and right sides of the screen. These displays show the balance between your energy production and energy consumption. If you consume the same amount of energy as you produce, the blocks are green, and everything is great. The blocks turn yellow when you produce a little more or a little less energy than you need. It is difficult to store energy for any length of time, so when the sliders are on the + side of these pools, you are wasting resources. The blocks turn red when either your production falls very short of consumption or you are producing far too much energy. When the slider is to the left and the block is red in your energy pools, you have fuel shortages, electrical brownouts, and freezing homes in the winter.

The graph located in the middle of the screen displays the amounts of your renewable and nonrenewable energy sources, as well as your Total Energy Demand (TED). As the population grows, so will the TED. Your energy production must keep up with the demand, or else the population will be wearing animal skins and living in caves. If shortages develop in either food or energy, a red bar will appear in the graph for those years in which the shortages exist. A major goal of the Simulator is to minimize (and hopefully eliminate) shortage years.

Personal Energy Demand (PED) shows the amount of energy each person uses per year. The number displayed is a multiple of the amount of energy needed to keep one person alive. The Energy Simulator starts with a PED of 95, which means the average person in the United States uses 95 times more energy than he or she needs to simply stay alive.

The Population block is self-explanatory. When you first start the Energy Simulator, your population will grow linearly at 1% per year. Next to Population is the Food Pool. As your population grows, you will have to devote more energy to agriculture in order to keep your people fed. If the slider moves to the right, you are producing too much food, and it's being wasted. If the slider moves to the left, your people are not getting enough food and possibly starving.

The bottom quarter of the screen shows all of the energy consumers: industry, transportation, home & commerce, and agriculture. These headings are broken down into sub-categories. Use the slide bars in each sub-category to control how much energy they use. The bottom slide bars let you adjust whether your population consumes electrical or chemical energy. If you move these slide bars, consider the impact on your populace. For example, if you move the Transportation slide bar from chemical to electrical, you are dumping all existing gasoline powered vehicles, and forcing people to build and buy electric cars, trucks, buses, and trains.

How to Work the Simulator

The Energy Simulator controls are easy and intuitive. All functions operate using the computer mouse. By moving the pointer into one of the boxes and either left-clicking (clicking the left mouse button) or right-clicking (clicking the right mouse button) you move the slide bars. Moving the slide bars changes energy production, energy consumption, and energy distribution between electrical and chemical.

The basic rule of operating the Energy Sim is this: Left-click on a box to move its slider to the left; right-click on a box to move its slider to the right.

The top menu bar controls many of the basic game functions. Left-clicking on the Help button brings up a screen that explains the basic operations of the simulator. In all the help screens, right-clicking the mouse button scrolls the text down, while left-clicking scrolls the text up. To bring up help text for individual blocks on the Energy Simulator screen, move the mouse pointer to the block and click both mouse buttons simultaneously. Exit the help screen by left-clicking on the part of the screen marked Exit This Screen.

The “no autostop” and “no sound” blocks control how the simulator reacts during a shortage situation. Left-clicking on these blocks changes them to AUTOSTOP and SOUND, respectively. With AUTOSTOP enabled, the simulator pauses when a shortage of either energy or food occurs. When SOUND is enabled, the computer speaker emits a warning beep when a shortage occurs to let you know things aren’t going well.

Clicking on the PERCENT command displays the percent use of your energy sources and your energy users. This command is an interesting reference, but is seldom used when operating the simulator.

The two commands to the right of PERCENT are ones you will use the most often when you run the Simulator. STDBY/oper represents “standby” and “operate.” Left-clicking on this command starts and pauses the simulator. After a successful (or unsuccessful) try, you use the RESET command to start over and try again. RESET performs different functions, depending on whether you use the left or right mouse button. Left-clicking on RESET restores years, population, and energy supplies, but it doesn’t affect any of your slide bar changes. Right-clicking on RESET restores *all* settings, numbers as well as slide bars, to their original values.

EXIT leaves the Energy Simulator program, bringing you back to the DOS prompt, or Windows 95.

A Short Tutorial

Before beginning with the exercises, practice working with the Energy Sim's controls. Move the mouse pointer to RESET at the upper right-hand part of the screen and click the right mouse button. You should always begin by doing this as it completely resets the simulator. The screen should look similar to Figure 1. The Chemical Energy, Electrical Energy, and Food Pools should all be green.

To change any of the production or consumption slide bars, move the mouse pointer to the specific block and right-click to increase and left-click to decrease. Move the pointer to the Coal block and right-click a few times. The coal slide bar moves to the right. What else happens? The Chemical Energy Pool slide bar also moves to the right, showing that you are now producing more energy than you need. Look also at Air Quality under Environmental Impact. Burning more coal releases more pollution into the air.

Now right-click in one of the energy consumer blocks at the bottom of the screen. Notice that the PED number increases, and the Chemical and Electrical Energy Pool slide bars move to the left. Left-clicking on these blocks reduces your demand and makes the PED go down.

The CH and EL slide bars below the energy sources and energy consumers control the type of energy (electrical or chemical) that you are producing or using. Slide those bars back and forth and note the effect on the simulator. Remember, right-click to increase, left-click to decrease.

Experiment with left- and right-clicking on the various blocks in the simulator. Left-click on the STDBY/oper button and begin. Click on that button again to stop the passage of time. When you and your partner have both had a turn at the controls, right-click the RESET button to initialize the simulator.

EXPERIMENTAL PROCEDURES

Part I —The "Do Nothing" Strategy

In this first part, you will do what the our political leaders now: you won't do anything. Make sure your Simulator is reset and click on the STDBY/oper button. You may want to enable the AUTOSTOP function to pause the simulator when you reach a shortage situation. Do not make any adjustments to the simulator; simply sit back and observe what happens to your energy supplies. After 100 years click on OPER/stdby and note the

state of the world's energy supply. Answer the following questions on a separate piece of paper:

1. How many years elapsed before energy shortages started developing?
2. What was the first energy source to run out? (Note: Do not look at the energy pools in the middle of the screen. Look at the energy sources: Oil, Natural Gas, Nuclear, etc.) Which source ran out next? Why are power companies pushing to use natural gas if it is going to run out so quickly?
3. How long did the Food Pool stay green? What would you have to do to keep the increasing population fed?
4. Make a rough sketch of the graph in the middle of the screen, labeling renewable and nonrenewable energy supplies, TED, and shortage years.

Now observe a variation of the "Do Nothing" plan. Move the mouse pointer to the Population block, and click both mouse buttons simultaneously. The window shown in Figure 113 should appear. Left click on the Initialize Values block to bring up another screen showing a graph. See Figure 114.

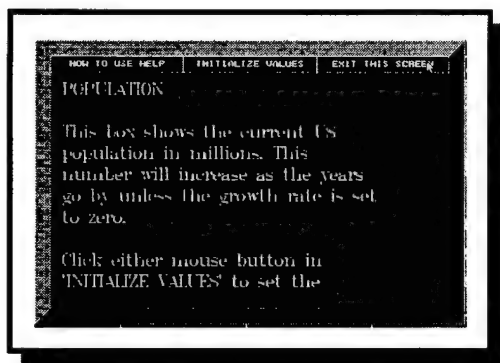


Figure 113. EES population information screen.

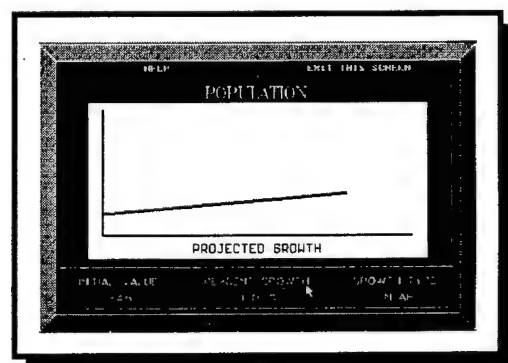


Figure 114. EES population growth rate screen.

Move the mouse pointer into the Percent Growth block. Left-click to decrease the growth rate until it is 0.0%. Click on Exit This Screen buttons until you are back to the main simulator screen. Reset the Sim (using the right mouse button) and run again for 100 years, observing but making no changes. Answer the following questions:

5. How long did the food and energy last when the population growth stopped?

6. Make a rough sketch of the graph in the middle of the screen, labeling renewable and nonrenewable energy supplies, TED, and shortage years.

Part II—Take Charge

Perhaps you have come to the conclusion that for this simulator the laissez-faire method doesn't work well. In Part II you and your partner will be in total control of how your population produces and consumes energy resources. Implement your policies to save the world's environment and energy supply. Reset the EES (keeping the population growth at 0%), start the EES, and do what you think is best. Stop the EES after 200 years have gone by. Try the EES a couple of times, and use your best results to answer the following questions:

7. Did you do better or worse than simply sitting by and watching? What went better and what went worse?
8. Make a rough sketch of the graph in the middle of the screen, and labeling renewable and non-renewable energy supplies, TED, and shortage years.

You should be getting better at running the world, so now let's make it a little more realistic. Change the population growth to 1.0% and run the Sim for 200 years again. Finally, change the growth from Linear to Exponential. Our population is presently exhibiting exponential growth. Run the Sim for 200 years and answer the following questions:

9. For both the linear and exponential population growths, make a rough sketch of the graph in the middle of the screen, labeling renewable and nonrenewable energy supplies, TED, and shortage years.
10. What flawed assumption does the simulator make concerning population growth?

Run the simulator three or four more times, changing whatever settings you want. When you finish, answer these last questions:

11. What is the best strategy to "beat" the Energy Sim? In other words, how can the human race survive indefinitely with plenty of energy and a healthy environment?
12. Do you think the Energy Simulator is an accurate model of our resources today? Why or why not?
13. Can we win the real game we are currently playing with our energy resources? Can we implement the strategy you described in question 11?

Environmental Impact

The three boxes in the upper left corner of the simulator screen present feedback on the environmental consequences of your actions. For example, increasing coal production makes the air quality change from "fair" to "poor." Answer the following questions regarding environmental impact.

14. Why does increasing coal usage cause the air quality to worsen? Write two chemical reactions involving coal (or impurities found in coal) that show the formation of air pollutants.
15. Why is unused heat a form of pollution? List and explain two harmful effects on a natural lake if its temperature were suddenly raised 10°C.
16. One of the most harmful by-products of nuclear fission is an isotope of strontium, ^{90}Sr . Why is this isotope particularly deadly to humans? (Hint: Consider the periodic table and another element that reacts in a similar manner to strontium.)

Conclusion

There are no "book answers" to many of the questions this exercise asks. The purpose of the EES is to raise questions, rather than provide answers, and get you to think about some difficult problems that we will face in the next 50 or 60 years. Are we doomed? Let us hope not. Are we in for some tough times ahead? Perhaps. Can you make a difference in what happens? Most definitely.

Laboratory Report

The report for this exercise will consist of three parts:

1. A brief description of you and your partner did during the lab period.
2. Answers to the 16 questions.
3. Answers to the following questions regarding your feelings about the energy environment simulator:
Was this exercise worthwhile? Was it a waste of time? How could we make it better? Did it increase your awareness of our energy problems and their potential solutions?

APPENDIX B

ADDITIONAL HP 48 PROGRAMS

Introduction

Chapter 5 of this thesis includes listings of several HP 48 programs. Programs and descriptions that were too long to Chapter 5 are provided in this appendix. The HP 48 programs described here are EZPRO, for student experiment design, PLNK, for obtaining data to determine Planck's constant, and the HP 48 colorimetry programs. Note that the HP 48 does not use line numbers in its programs. The line numbers provided in the program listings are for reference only.

EZPRO

Experiment design capability on the HP 48 is implemented by allowing students to choose from a list of sensors in a manner similar to the LabWorks EZ Program. Rather than build an experiment from scratch, the HP 48 program, EZPRO, integrates the student choices and into a preexisting program. The program listing is as follows:

| Line # | HP 48 Commands |
|--------|--|
| 1 | "FIRST INPUT" |
| 2 | { {Time 0 } { Counts 1 } { I1 2 } {Kelvin1 3 } { pH1 4 } } |
| 3 | 1 CHOOSE DROP |
| 4 | "Second INPUT" |
| 5 | { {None 0 } { Counts 1 } { I1 2 } {Kelvin1 3 } { pH1 4 } } |
| 6 | 1 CHOOSE DROP |

| | |
|----|---|
| 7 | → x y CASE |
| 8 | 'x == 0' 'y == 0' AND THEN TIMER END |
| 9 | 'x == 1' 'y == 0' AND THEN COUNTER END |
| 10 | 'x == 2' 'y == 0' AND THEN I1SUB END |
| 11 | 'x == 3' 'y == 0' AND THEN KELVIN1 END |
| 12 | 'x == 4' 'y == 0' AND THEN pH1 END |
| 13 | 'x == 0' 'y == 1' AND THEN TIMCTR END |
| 14 | 'x == 0' 'y == 2' AND THEN TIMI1 END |
| 15 | 'x == 0' 'y == 3' AND THEN TIMKEL1 END |
| 16 | 'x == 0' 'y == 4' AND THEN TIMpH1 END |
| 17 | 'x == 1' 'y == 4' AND THEN CNTpH1 END |
| 18 | 'x == 1' 'y == 3' AND THEN CNTKEL1 END |
| 19 | 'x == 1' 'y == 2' AND THEN CNTI1 END |
| 20 | CLLCD "Invalid Choice – Try Again" MSGBOX END |

HP 48 Program 10. Student experiment design using the HP 48.

Lines 1 through 3 of the program build the first choice box and assign a numerical value to each of the choices. Lines 4 through 6 build a second choice box, and again assign numerical values to the choices. The values given to each choice are assigned to the local variables x and y in line 7. The CASE statement initializes the parameters that activate a specific program, based on the user's choices. Lines 8 through 19 launch the desired program, using the values of x and y in a Boolean true/false statement. Line 20 is the default option, which displays an error message if the user's choices do not match an existing program.

PLNK

The HP 48 program PLNK acquires data to experimentally determine Planck's constant. This procedure is discussed in Chapter 5 and used in the student experiment in Chapter 9. Users input the wavelength of the LED they have attached to the LabWorks interface, and this value is converted to frequency and stored. The program then increments the voltage to the LabWorks digital-to-analog converter (DAC) while simultaneously measuring electric current through the LED. At 0.1 μA of current the excitation voltage and frequency are saved in a data array. The program continues to increase voltage to allow users to illuminate the LED. Users may measure the excitation current of multiple LEDs, but at least two measurements are required to get linear regression information from their data.

The PLNK program is shown below as HP 48 Program 11:

| Line # | HP 48 Commands |
|--------|--|
| 1 | "Enter LED wavelength in nm" " " INPUT OBJ→ |
| 2 | 2.99792458e17 SWAP / 'NU' STO |
| 3 | 2500 'M' STO |
| 4 | DO M 15 + 'M' STO |
| 5 | DAC1 |
| 6 | M 0.00122424 * 2.5065 - "DAC V" → TAG 2 DISP |
| 7 | I1SUB " μA " → TAG 3 DISP |
| 8 | UNTIL 'I \geq 0.05' END |

| | |
|----|--|
| 9 | DO M 1 + 'M' STO |
| 10 | DAC1 |
| 11 | M 0.00122424 * 2.5065 - "DAC V" → TAG 2 DISP |
| 12 | I1SUB "μA" → TAG 3 DISP |
| 13 | UNTIL 'I ≥ 0.1' END |
| 14 | M 0.00122424 * 2.5065 - |
| 15 | 1.602E-19 * 'E' STO |
| 16 | DO M 10 + 'M' STO |
| 17 | DAC1 |
| 18 | M 0.00122424 * 2.5065 - "DAC V" → TAG 2 DISP |
| 19 | I1SUB "μA" → TAG 3 DISP |
| 20 | UNTIL 'I ≥ 2000' END |
| 21 | DATA NU E |
| 22 | →V2 2 ROW+ 'DATA' STO |

HP 48 Program 11. Program used to acquire data for calculating Planck's constant.

Line 1 of the program prompts users to type in the wavelength of the LED being used and converts this input into a real number. The wavelength is then converted to frequency, and saved in the global variable NU in line 2.

Line 3 creates a global variable, M, that will be used to set the value of the LabWorks interface DAC1. An M value of 2500 sets the DAC to 0.5 volts, according to the formula explained in Chapter 5. Line 4 starts a DO...UNTIL loop that increments the DAC and reads current from the LabWorks interface's I1 input. The DAC1 subroutine in Line 5 converts M to a binary number and sets DAC1 according the value of M. This

subroutine is similar to the program listed in Chapter 5 as HP 48 Program 4. Line 6 displays the current DAC reading using M, and line 7 reads and displays the current from I1. The DAC voltage will increase by 0.018 volts until the current reading reaches 0.05 microamps.

When the input from I1 is greater than or equal to 0.05 microamps, Line 9 starts another DO...UNTIL loop that increments the DAC in approximately 1 millivolt steps. Lines 11 and 12 continue to display the DAC voltage and I1 current. When the current reading is greater than or equal to 0.1 microamps, the DAC voltage is converted to joules by line 15, and stored in the global variable, E.

Line 16 starts a third DO...UNTIL loop that increments DAC1 by 10 millivolts until the current reading is greater than or equal to 2000 microamps. When the last loop finishes, the values of the variables NU and E are added to the array, DATA, created by PLINI. The number of LEDs measured by this program is limited only by calculator memory.

HP 48 Colorimeter Programs

The HP 48 colorimeter is used in the experiment, "Colorimetry and Determination of Chlorine Concentration" detailed in Chapter 9. Students activate three programs in the course of calibrating their colorimeters, measuring the absorbance of their standards, and analyzing their unknowns. These programs are CALCO, MEAS, and UKN. The program listings and line-by-line descriptions are given in this section.

CALCO

The HP 48 program that students use to calibrate their colorimeters is given as

HP 48 Program 12:

| Line # | HP 48 Commands |
|--------|--|
| 1 | INICOL |
| 2 | "Put water cuvette in the colorimeter – |
| 3 | Press 'OK' to calibrate." MSGBOX |
| 4 | 1 10 START I1SUB " μ A" →TAG 2 DISP .5 WAIT NEXT |
| 5 | 'T100' STO |
| 6 | "Calibration OK. Run MEAS to take readings." |
| 7 | MSGBOX |

HP 48 Program 12. Colorimeter calibration program.

The INICOL in line 1 is a subroutine that initializes the LabWorks interface and creates an array for data storage. It is almost identical to HP 48 Program 8, which initializes the interface for gathering Planck's constant data. Lines 2 and 3 generate a message box that instructs students to place a cuvette of distilled water in the colorimeter for calibration.

Line 4 reads current from the I1 input using I1SUB and displays the output, allowing students to confirm that their current readings have stabilized. Line 5 takes the input from I1 and stores it in a global variable, T100. This is the 100 percent transmittance value, and will be used to calculate absorbance for the other readings.

Lines 6 and 7 then flash another message box to tell students that the calibration is complete.

MEAS

After students calibrate their colorimeters and make their standard solutions, they are ready to obtain colorimetry data on these standards. MEAS, listed as HP 48 Program 13, performs this function:

| Line # | HP 48 Commands |
|--------|---|
| 1 | DO |
| 2 | "Enter solution concentration" " " INPUT OBJ→ C STO |
| 3 | "Place cuvette of standard solution in colorimeter – |
| 4 | Press OK to measure." MSGBOX |
| 5 | 1 10 START I1SUB T100 / LOG -1 * |
| 6 | "Absorbance" →TAG CLLCD 1 DISP .5 WAIT NEXT |
| 7 | I1SUB T100 / LOG -1 * 'A' STO |
| 8 | DATA A C →V2 2 ROW+ 'DATA' STO |
| 9 | "Enter 1 to take another reading or 2 to stop the program." |
| 10 | " " INPUT OBJ→ 'TST' STO |
| 11 | UNTIL 'TST ≠ 1' END |

HP 48 Program 13. Colorimeter measurement program.

The program runs in a DO...UNTIL loop and will repeat until the test condition is met. Line 1 contains the DO statement, and the conditional test is in line 11. The rest of

the program is part of this conditional loop, allowing students to make as many measurements as they want.

Line 2 prompts students to manually enter the concentration of the standard solution they are reading, and this value is stored as a variable C. Lines 3 and 4 prompt students to place the cuvette of standard solution in the colorimeter, and press OK on the calculator to make the measurement.

Line 5 reads input from I1 and converts this reading to absorbance using the T100 variable created by INICOL. This measurement is displayed 10 times, allowing students to make sure their readings have stabilized. The readings are then stored in the variable A in line 7.

Line 8 takes the variables C and A and adds them to the data array created by INICOL. Every time a new reading is made the concentration and absorbance values are added to the data array. Students are prompted to enter 1 to make another reading, or 2 to stop the program by line 9. Line 10 saves the student input to a variable TST. Finally, line 11 either ends the program or begins the loop again, depending on the value of TST. While students are prompted to enter either a 1 or a 2, the program will end on any value other than 1.

UKN

The final colorimeter program students will run is UKN. They will use this program to measure the absorbance of their unknown solution, and then calculate the

unknown's concentration, using the calibration information they gathered using MEAS.

UKN is listed as HP 48 Program 14:

| Line # | HP 48 Commands |
|--------|--|
| 1 | DATA 1 ROW- DROP 'ΣDAT' STO |
| 2 | "Place cuvette of unknown in the colorimeter – |
| 3 | Press OK to measure." MSGBOX |
| 4 | 1 10 START IISUB 100 / LOG -1 * |
| 5 | "Absorbance" →TAG CLLCD 1 DISP .5 WAIT NEXT |
| 6 | LR 1 DISP |
| 7 | DTAG "Int." →TAG 2 DISP |
| 8 | CORR "Corr." →TAG 3 DISP |
| 9 | IISUB T100 / LOG -1 * PREDY |
| 10 | "Conc" →TAG 4 DISP |
| 11 | 7 FREEZE |

HP 48 Program 14. Finding the concentration of the unknown solution.

Line 1 removes the (0, 0) point that CALCO used to create the data array and stores the array into a special variable, ΣDAT. Students are then prompted by lines 2 and 3 to place their cuvettes containing the unknown solution in the colorimeter. Like the first two colorimeter programs, 10 measurements are made and displayed to let students confirm that their readings have stabilized. These readings occur in line 5.

Line 6 uses the HP 48 linear regression function LR to find the slope and intercept of the calibration data, which has already been saved in Σ DAT. The slope, intercept, and correlation coefficient are displayed by lines 6, 7, and 8.

Line 9 makes a current reading of the unknown, converts it to absorbance, and uses the HP 48 function PREDY (predict y-value) to use the calibration line to find the concentration. This concentration value is displayed in line 10. Line 11 freezes the display, allowing students to copy these values to their data sheets.

APPENDIX C

OUTLINES OF TRADITIONAL AND DISCOVERY-BASED
COLORIMETRY EXPERIMENTS

Introduction

Chapter 11 of this thesis presented survey results that compared discovery-based and traditional versions of the same experiment. The experiment used was “Colorimetry and Determination of Nitrate Ion Concentration.” This experiment was used in the Chemistry 121 and 131 laboratory courses and Montana State University.

To compare student learning and enjoyment of the two learning methods, this experiment was re-written to incorporate inquiry-based learning strategies. As explained in Chapter 11, half of the laboratory course used the traditional version of the experiment, and the other half of the course used the new version. There are two important differences between the two experiments.

The first difference involves determining the colorimeter light source color. In the traditional experiment, students are instructed to use the green LED as a colorimeter light source. The discovery-based version requires students to look at spectral charts for different-colored solutions, and then hypothesize the best light source color. Students are then encouraged to test their hypothesis by measuring percent transmittance of the same solution with different LED colors. These actions engage students in experiment design, allowing them to learn at the analysis and synthesis levels of Bloom’s taxonomy.

The second difference between the two types of experiments is that the discovery-based version incorporates different real-world applications into the experiment procedure. After practicing their colorimetry technique on a red food coloring solution,

students answer a question in either biomedical, agricultural, or environmental science.

All problems involve measuring nitrate ion concentration in solution, but the reasons for finding the concentration are different for every problem. Chapter 7 explained that the applications act further to draw the students into the laboratory experience by making the procedures meaningful to them, personally.

Figure 115 is a block diagram that outlines the student actions for the traditional experiment. These experiment actions follow a linear course with few opportunities for experiment design actions which promote higher-level learning.

Figure 116 shows the student actions performed in the discovery-based version of the experiment. Students must determine which light source color to use, and solve a specific application-based problem.

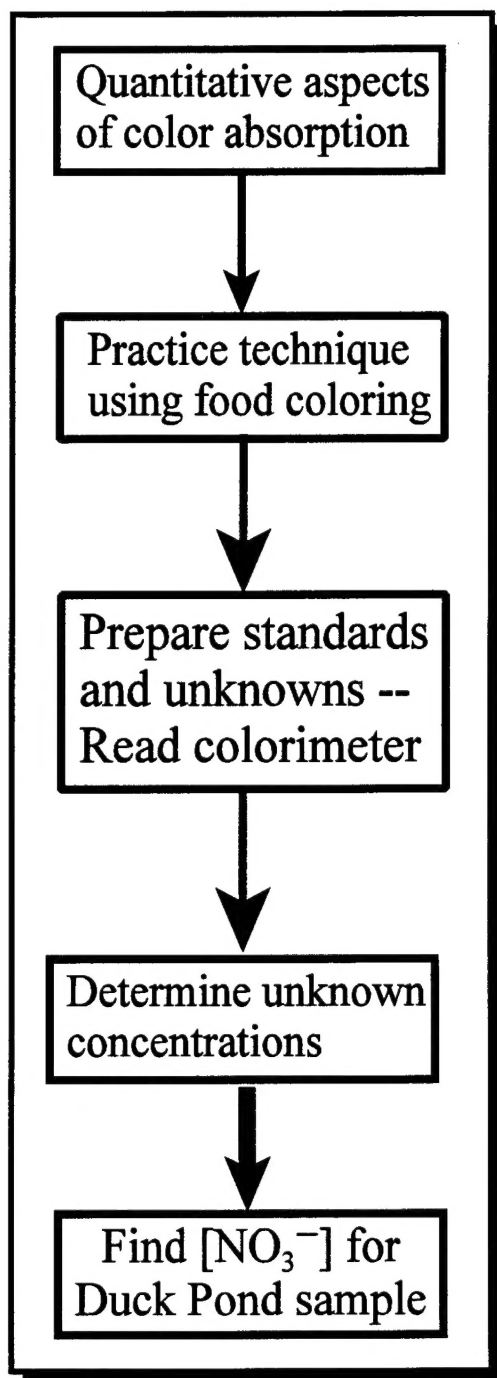


Figure 115. Activity flow chart for traditional colorimetry experiment.

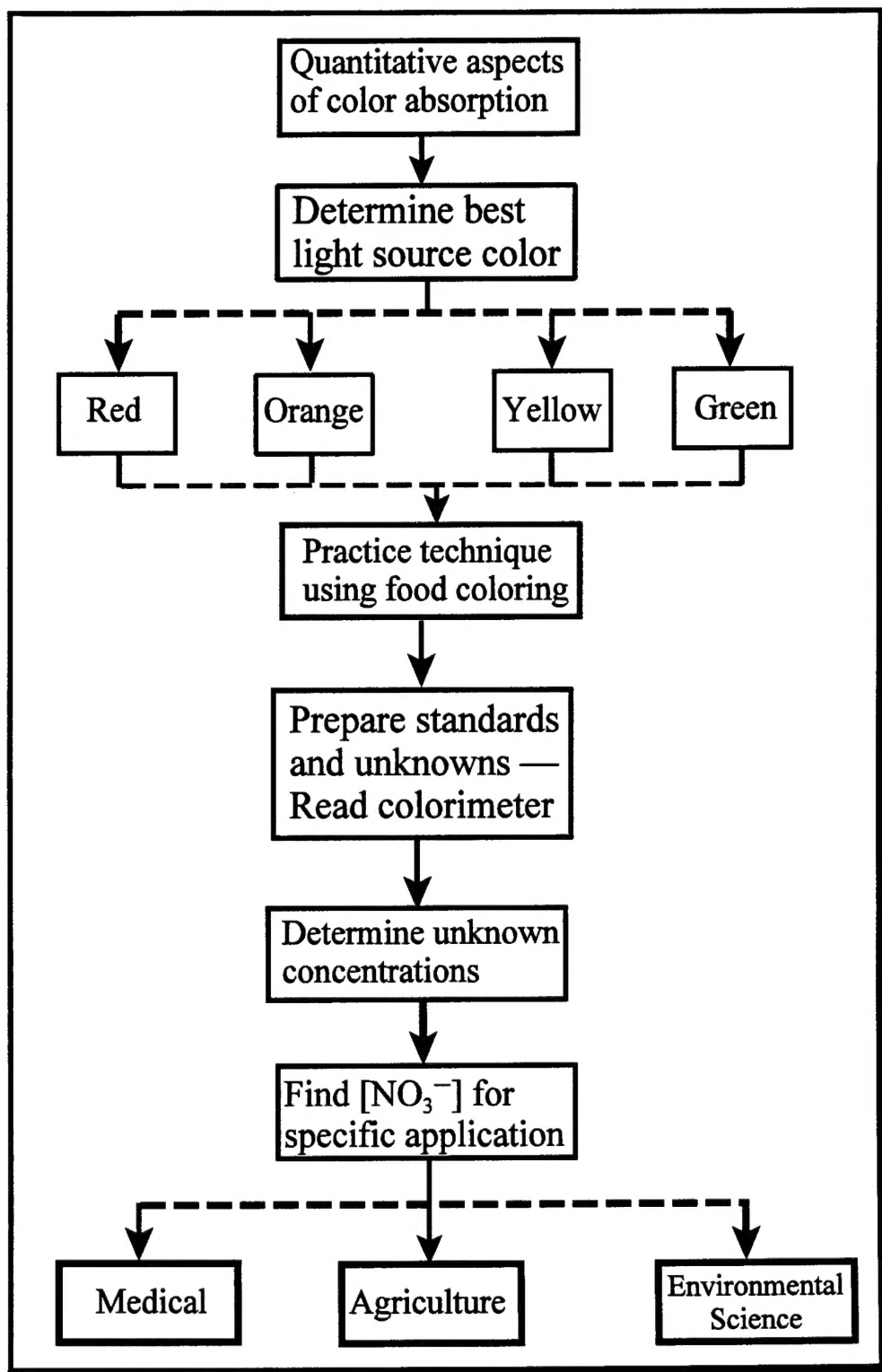


Figure 116. Activity flow chart for discovery-based colorimetry experiment.